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Study of the Arctic Heat Sink

by

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ABSTRACT

The objectives of this study were:

- to document the variability of the Arctic heat sink;
- to investigate possible effects of these variations on northern hemispheric circulation patterns; and
- to look for relationships between Arctic heat sink variations and sea-surface temperature anomalies.

To meet these objectives, several characterizations of the Arctic heat sink have been proposed; the relevant datasets for investigating these characterizations are either provided or described; and preliminary analyses of the relationships between variations in the Arctic heat sink (in accordance with these characterizations), sea-surface temperature anomalies, and circulation patterns are presented.

RÉSUMÉ

Les objectifs de cette étude étaient:

- de documenter la variabilité du puits thermique arctique;
- d'examiner les effets possibles de ces variations sur la circulation dans l'hémisphère nord; et
- de trouver des relations entre les variations du puits thermique arctique et les anomalies de température à la surface de la mer.

Pour atteindre ces objectifs, on a proposé de caractériser plusieurs paramètres du puits thermique arctique, on fournit ou décrit les ensembles de données pertinents à cette caractérisation; et on présente les analyses préliminaires des relations entre les variations du puits thermique arctique (selon cette caractérisation), les anomalies de température à la surface de la mer et la circulation.

LIST OF ACRONYMS

AHS	Arctic heat sink
COADS	Comprehensive Ocean-Atmosphere Dataset
ECMWF	European Centre for Medium Range Weather Forecasts
MMC	mean meridional circulation
MMCHF	mean meridional circulation heat flux
NCAR	National Center for Atmospheric Research
NEDN	Naval Environmental Data Network
NESDIS	National Environmental, Satellite, Data, and Information Service
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
OLR	outgoing longwave radiation
SLP	sea-level pressure
SST	sea-surface temperature

Table of Contents

	Page
ABSTRACT	i
LIST OF ACRONYMS	ii
INTRODUCTION	1
DEFINITIONS OF THE ARCTIC HEAT SINK	1
DATASETS	4
• Ice and Snow Cover	
• Surface Temperature and Upper-Air Data	
• Clouds	
• Sea-Surface Temperature	
• Soil Moisture	
• Streamflow	
DATA ANALYSIS	7
• Arctic Heat Sink Climatology	
—Snow and ice cover	
—100-70 kPa thickness	
—Mean surface temperature	
—Mean meridional circulation heat flux	
• Relationships Between the Arctic Heat Sink, North Pacific Sea Surface Temperatures, and Anomalies in Circulation and Precipitation on the Canadian Prairies	
—Correlations between the AHS indices	
—Correlations between the AHS indices and North Pacific SST anomalies	
—Correlations between the AHS indices and 70 kPa geopotential anomalies	
—Arctic ice concentrations composited with respect to Canadian Prairie precipitation	
—Northern hemisphere SLPs and 70-kPa heights composited with respect to Canadian Prairie temperature and precipitation	
SUMMARY	14
RECOMMENDATIONS	14
ACKNOWLEDGEMENTS	16

REFERENCES	16
FIGURES	19
APPENDIX	C1

INTRODUCTION

A recent report on Canadian Prairie drought prediction (Ripley, 1988) recommended that studies be made looking for possible relationships between anomalous large-scale surface boundary conditions and drought occurrence. The most likely candidate predictors were considered to be surface temperature, soil moisture, and snow and ice cover.

Variations in these factors modify the surface-atmosphere exchanges of energy and moisture, which are believed to affect the atmospheric circulation and in turn the evolution and movement of synoptic systems. Sea-surface temperature anomalies in the tropics have been found to be closely linked to anomalies in circulation and precipitation over some sub-tropical regions, and may affect the mid-latitudes as well (Cayan and Peterson, 1989).

In the extra-tropics, major influences have been related to both soil moisture (Shukla and Mintz, 1982) and snow cover (Kukla, 1981) anomalies. These have not yet been fully explored with respect to drought on the Canadian Prairies.

In order to analyze these possible relationships, it is necessary to obtain the best-possible datasets of the relevant parameters, for as long periods of time as possible. The present study focusses on the region near the north pole that loses heat by radiation, and acts as a sink for the surplus radiant energy transported from the tropics by the general circulation. This region will be termed the Arctic heat sink (AHS) in this report. The "strength" of the AHS (i.e. rate of heat loss from the Arctic) varies from year to year, and during each year itself. There also may be significant variations in the spatial distribution of the heat losses within the Arctic region itself. While no direct measurements of the Arctic heat sink exist, proxy data are available. These include: surface (or near surface) temperatures, outgoing longwave radiation, and ice and snow cover. Since each of these is available in a different form, for a different length of time, and for a different geographical area, there is no ideal predictor.

Although this analysis focusses on possible effects of Arctic surface anomalies on Canadian Prairie precipitation, it is recognized that other boundary forcings, such as Pacific Ocean SST, and North American grain belt soil moisture, anomalies may have similar or larger influences. Reference to these other forcings will be made from time to time in the main body of this report, as well as in the recommendations.

DEFINITIONS OF THE ARCTIC HEAT SINK

The global "heat engine" transfers surplus energy from the tropics to the polar regions by means of atmospheric and oceanic circulations. Despite the polar "heat sink" regions occupying only one fifth the area of the tropical "heat sources", and

having thermal characteristics modulated by ice and snow, they play a very important role in this large-scale energy transfer (Goody, 1980).

Although radiation income from the sun has a predictable seasonal pattern, with little interannual variability, other energy-balance terms are affected considerably by surface conditions. In the Arctic, the most important of these is oceanic ice cover. Maykut (1978) has shown that mid-winter heat loss (by radiation, convection and evaporation) from the Arctic Ocean is reduced 50 percent by as little as 5 cm of ice cover, while a typical mature ice cover, of about 3 m thickness, has less than 2 percent of the heat loss of open water. For land surfaces, snow provides excellent insulation against sensible heat loss, although none against latent heat loss through sublimation. However both ice and snow have very high albedos (0.6 to 0.8) that result in much lower solar radiation absorption than open sea or land surfaces (albedos of 0.06 to 0.15). This reduced absorption results in a reduction of the driving force for all forms of heat loss. Further, the loss of ice and snow covers require considerable amounts of energy to produce the phase changes from solid or liquid to the gaseous form needed for diffusion into the overlying air. It is because of these properties of ice and snow covers, and their complex transformations and temporal variations, that polar regions exert an influence far out of proportion to their surface area (Goody, 1980).

It is conceivable that variations in snow and ice cover modulate the strength of the polar heat sinks (Weller, 1980; Walsh and Johnston, 1979A), and can produce changes in atmospheric circulation, and hence weather, in other parts of the globe. Studies by Walker (1947), Lamb (1955), Wahl (1968), and Walsh and Johnson (1979B) have shown relationships between snow and ice cover and surface and upper-air temperature and pressure fields. Foster et al. (1983) found a high correlation between autumn snow cover in Eurasia and subsequent winter air temperatures in the central USSR. Connections have been noted between snow cover and "blocking" (Namias, 1964), and Himalayan snow cover and the intensity of the Indian monsoon (Hahn and Shukla, 1976).

Ideally, the Arctic heat sink should be described by a time series of spatial maps of the downward flux of energy at the surface. Not only are there inter and intra-annual variations in the area involved, but also in the sink strengths at each location. For any analytical study, however, it is necessary to define a particular "Arctic heat sink" region. The region north of the 70th parallel encompasses most of the Arctic Ocean (Fig. 1), although sea ice, and certainly snow cover, are often found as far south as 40 degrees. Many other studies have used either the Arctic Circle (e.g. Goody, 1980), or north of the 60th parallel (Walsh and Johnson, 1979B) as the boundary. The latter will be used as much as possible in the present study.

Four methods of characterizing the Arctic heat sink are being proposed. Each has different temporal and spatial limitations on data availability. It will be desirable to test the usefulness of

each of the methods as potential predictors, and as well to compare them with one another for consistency.

The first method specifies the heat sink in terms of the meridional energy fluxes at 60°N integrated from the surface to about 10 kPa. This is a direct measure of the flux from lower latitudes into the Arctic, and should include all forms of energy. However, since the eddy fluxes of sensible (and to a lesser extent, latent) heat dominate the transfer at that latitude (Fig. 2), it should be adequate to specify the heat sink in terms of these fluxes alone (average values of which are shown in Figure 2).

Required for these calculations are daily values of vertical profiles of meridional wind, temperature and humidity along the 60th parallel. The most suitable data will likely come from gridded analyses, which are available from the mid-1960s from the National Center for Atmospheric Research (NCAR) and the National Meteorological Center (NMC).

The second method also involves the use of upper-air data. This is simply the thickness of the 100-85 or 100-70 kPa layer over the region 60°N to the pole. Since thickness is directly related to density (and hence temperature) through the hydrostatic equation, this provides a spatially-averaged estimate of a near-surface temperature for the region. Use of this indicator is based on the assumption that the strength of the AHS is closely related to the surface temperature. The mean temperature of the lowest atmospheric layer is more readily available than surface temperature data, and may be used instead of it. Either mean monthly station or gridded data would be suitable, although the latter is preferable. Suitable data are available from NCAR and NMC covering the period since the mid-1940s.

The third method uses gridded sea-ice and snow-cover datasets. The most useful Arctic sea ice dataset is the one prepared by Walsh (1978), which was recently updated so that it covers the period 1953-1986. It provides ice concentrations, in tenths, for each 60 x 60 nautical mile grid cell shown in Figure 1. A dataset of northern circumpolar ice limit for the years 1901 to 1956, digitized by Kelly (1979), may be of supplementary value.

Ice thickness data are too scarce to be of much value in the present study. If they were available, it would be possible to parameterize the Arctic Ocean heat sink in terms of area of open water and ice amount and thickness.

The NOAA/NESDIS northern hemisphere snow and ice cover dataset, described by Dewey and Heim (1982), has been obtained for the period 1966-1988. It comprises weekly data gridded with 250 km resolution.

The fourth method specifies the Arctic heat sink in terms of Arctic surface temperatures, either measured directly or derived from satellite measurements of outgoing longwave radiation (OLR). A copy of the 1851-1984 global grid point surface air temperature

data set of Jones et al. (1985) has been obtained. About fifteen years of satellite data are also available (Jenne and McKee, 1985).

Each of the above heat sink "indices" should be prepared in the form of a time series of monthly values. The anomalies of these values then form the bases for further analyses.

In summary, then the proposed AHS indicators are:

1. Ice and snow covers--these indicate the area of the Arctic over which the sensible and latent heat transfers are modulated by the presence of ice and/or snow and where the radiation transfer is affected by the optical characteristics of the ice or snow surface.
2. Lower tropospheric thickness--this indicates the temperature of the surface atmospheric layer (and hence the surface), which is related to the strength of the heat sink.
3. Surface temperature--this is an estimate of the surface temperature, as above, using surface, rather than upper air, data.
4. Meridional heat transport--this is a direct measure of the heat flux, from lower latitudes, which is moving towards the Arctic and will flow into the Arctic heat sink.

DATASETS

The preliminary analyses carried out in the present study use monthly average data, rather than shorter period (weekly, daily) data which may be more desirable for certain type of analyses.

The relevant data include, then, monthly time series of Arctic ice and snow cover, temperature, geopotential, and northern hemisphere geopotential and sea-surface temperatures.

The datasets considered necessary to carry out the analyses are described below. Those actually provided, as well as those recommended for acquisition, are described in the Appendix.

The required data may be classified into two types: that defining the forcing parameters such as sea-surface temperatures, soil moisture, Arctic heat sink, and that defining the forced parameters, or drought indicators, such as precipitation, runoff, soil moisture.

Forcing Parameters

Ice and Snow Cover

The most desirable ice and snow cover data would be gridded, and would cover the entire northern hemisphere for a period in excess

of fifty years. Unfortunately, data satisfying all of these criteria are not yet available. The closest approximation is the NOAA/NESDIS northern hemisphere snow and ice cover dataset (Dewey and Heim, 1982; Scialdone and Robock, 1987). This dataset comprises weekly data for the period 1966-87, gridded with 250 km resolution. Each grid-cell is coded 0 or 1 on the basis of whether it is more or less than half covered with ice or snow. Data are missing during the dark polar-winter period.

A dataset of the northern hemisphere circumpolar ice limit, for the years 1901-1956, maintained by the Danish Meteorological Institute, has recently been digitized by Kelly (1979), using a 100 km grid.

The most useful Arctic sea-ice dataset is one prepared by Walsh (1978), which covers the 1953-1986 time period. The data provide concentrations in tenths, for each 60 x 60 nautical mile grid square, on a monthly basis.

The best data for continental snow cover are likely to be those collected by Canada's meteorological service, which are available for the past 40-50 years at about 150 stations (Walsh, personal communication). These include monthly snowfall amounts and end-of-month accumulated depths. Data for other polar countries (U.S.A., U.S.S.R., etc.) may also be used. Some difficulties are likely because of the different measurement methods used in different countries.

Surface Temperature and Upper-Air Data

Reliable surface temperature data have been collected for about 100 years at many stations, and gridded datasets for the northern hemisphere have been prepared by groups in the United States (Hansen and Lebedeff, 1987, 1988), Great Britain (Jones et al., 1985) and the U.S.S.R. (Vinnikov et al., 1980). The U.K. dataset is gridded on a 5° latitude x 10° longitude grid and is probably the easiest to use.

In some respects a better indicator of temperatures over large geographical areas (particularly in areas with sparse station coverage), outgoing longwave radiation (OLR) has been measured from satellites since 1973 (Jenne and McKee, 1985).

Upper-air temperatures have been measured in a comprehensive manner for about the past 40 years. Gridded analyses are available from a number of sources (Jenne and McKee, 1985). One possibility would be to use surface-to-85 kPa thickness as an Arctic heat sink indicator.

Upper-air height-pressure data, to specify the atmospheric circulation, are available for the past 40-50 years from a number of sources.

The Comprehensive Ocean-Atmosphere Dataset (COADS) provides gridded (both 2° and 4° grids) data for eight parameters (including air and sea temperatures) on a monthly basis as far

back as the 1850s (Woodruff et al., 1987). A new release of the dataset is expected later this year.

The Naval Environmental Data Network (NEDN) dataset (KelResearch Corp., 1985) comprises gridded data (381 km spacing) derived from analyses, since 1974. The dataset includes a large number of parameters, of which air and sea-surface temperatures are the most relevant here.

Clouds

Clouds are not easily observed by eye during the night or during the polar winter, nor are the usual point observations easily extrapolated to large geographical areas. However, some of the datasets described above include cloud estimations derived from either station observations (NEDN and COADS) or satellite data.

Sea-Surface Temperature

Most of the datasets described above, that involve measurements in marine areas, include sea-surface temperature data. These have been derived from ship reports since the mid-1800s and processed in a number of different ways. A discussion of some of the errors involved in these measurements, and long-term trends in the data, may be found in Barnett (1984). Monthly sea-surface temperature data are available, from Scripps Institution, since late 1973, gridded at 2° - 5° resolution.

A dataset of monthly-average SSTs covering the period from 1947 to the present, for the North Pacific Ocean (60°-90°N, 130°E-110°W) has been obtained from Dan Cayan at Scripps Institution (Namias et al., 1988).

Soil Moisture

It is highly unlikely that any soil moisture datasets, of sufficient geographic or temporal extent to be useful in a forcing analysis, will be found. Thus proxy data will be required, most likely based on measured meteorological variables.

Forced parameters

The main source of data for indicating Canadian Prairie drought occurrence is the Atmospheric Environment Service climatological data archives. For some purposes, a gridded derivative of these data (Skinner, 1987) may prove useful.

Canadian Prairie Soil Moisture Datasets

Soil moisture data are available from 35 sites in southern Manitoba and Saskatchewan (Manitoba Natural Resources, 1988) collected in the late autumn of each year since 1955. Other similar datasets are being sought.

Canadian Prairie Streamflow Data

Flows from uncontrolled streams in the Canadian Prairies, and adjacent areas, are available from a number of sources (e.g. Sargent, 1989).

DATA ANALYSIS

Arctic Heat Sink Climatology

Snow and ice cover

When land surfaces become covered with snow, there is a dramatic change in their surface albedo, and in the resistance to heat and mass exchange between the surface and the atmosphere. Similarly, when a layer of ice forms on a water surface, the optical characteristics and heat and mass exchange are profoundly affected as well.

On average, snow and ice covers exhibit pronounced seasonal variations. In the northern hemisphere, both reach their maximum extent in February, and diminish to their least extent in August (Fig. 3). The variation with latitude is considerable, with ice covering over 90% of the sea surface north of 79°N, in winter and north of 84°N in summer (Fig. 4). Land snow cover extends much farther equatorward, with latitude 35° averaging more than 20% cover in mid-winter, although it would be necessary to go northward to 72° to find that much snow in mid-summer (Fig. 5). A comparison of the isoline spacing on Figures 4 and 5 indicates the more rapid growth and decay of the snow cover in comparison to the sea ice.

Figure 6 shows the winter-season snow cover frequency over the northern hemisphere as the percentage of winter-season weeks having snow cover. The furthest southward penetration of the 100% area is in eastern Canada, while the 0-24% category reaches its southernmost limit on the Tibetan Plateau. Monthly variations in the geographical areas covered by snow are shown in Figure 7. Interannual differences in these covers can be considerable.

Year-to-year variations in Arctic ice concentration, from the monthly dataset of Walsh (1978), are shown in Figure 8. The ordinate is tenths of 1° square grid cells that are covered with ice. Thus, the mid-winter values of about 12000 in Figure 8 correspond to an ice cover of 15 Mm² (as in Fig. 3). When the mean monthly ice concentration values are subtracted from the data in Figure 8, the resulting anomalies (Fig. 9) show the seasonally-adjusted departures from average. Some long-period departures from average are evident--periods of more extensive ice during the late 1950s and late 1960s, and less than average cover since the early 1970s.

The NOAA/NESDIS dataset (Dewey and Heim, 1982) gives monthly, and weekly snow plus ice cover in terms of numbers of 2° (approximately) square grid cells more than half covered with ice

or snow. Unfortunately, after 1980 the data no longer include ice. Figure 10 shows a time series of the monthly values, which have a mean, standard deviation and coefficient of 1083, 577 and 0.53 for the 1966-1979 period (snow plus ice), and 776, 509 and 0.66 for the 1980-1988 period (snow only). Comparison of the coefficients of variation confirm the greater variability of the snow cover, noted earlier. Monthly anomalies, for the two sub periods are shown in Figure 11.

100-70 kPa thickness

The difference in height between any two isobaric levels in the atmosphere, or "thickness" of that layer, is directly proportional to the mean absolute temperature of the layer. Manipulation of the hydrostatic law:

$$dp = \rho g dz$$

and ideal gas law:

$$p = \rho R T$$

leads to an expression for the thickness of the layer between pressure levels p_1 and p_2 :

$$\delta z = (R/g) \int_{p_1}^{p_2} (T/p) dp$$

In the above equations, p stands for atmospheric pressure, ρ for air density, g for the acceleration of gravity, z for height above the surface, R for the Gas Constant, and T for temperature in kelvin.

Upper-air analyses provide geopotential heights for a number of pressure levels. Here, the heights for 100 and 70 kPa have been subtracted to yield 100-70 kPa thicknesses, which are proxy data for the mean temperature of this lowest third of the atmosphere.

Average thickness values were subtracted from the original data to yield monthly anomalies to be used in the subsequent analyses. A 42-year time series of these data, for the Arctic region, is shown in Figure 12. This region is defined as covering that portion of the northern hemisphere between latitudes 65 and 80.

Mean surface temperature

The northern hemisphere monthly grid-point temperature dataset of Jones et al. (1985) is expressed as departures from the 1951-1970 means. A time-series plot, for 1851-1987, of the average anomalies between latitude 65° and the pole is presented in Figure 13.

Greater variability before 1900 is undoubtedly related to the lower number of observing stations during that period. A general preponderance of positive anomalies indicates that the 1950s and 1960s were a relatively cool period in the polar region. The warmest periods appear to have been the mid-19th century (although this may be an artifact of the paucity of observing stations at that time), the 1890s, the 1920s to 1950s, and since 1970. Cool periods around 1900 and 1970 are also noticeable.

Mean meridional circulation heat flux

The Arctic heat sink may be specified in terms of the total meridional energy flow across a line of latitude such as the Arctic Circle. The meridional transport of sensible heat may be broken down into components due to the mean meridional circulation (MMC), to standing eddies, and to transient eddies. At low latitudes the MMC component dominates, but as the pole is approached the eddy components become more important.

The meridional heat fluxes, across any latitude, may be calculated from upper-air geopotential data (Oort and Rasmusson, 1971). While the MMC component may be calculated from mean monthly data, daily (or shorter period) data are required to calculate the higher-frequency eddy components. While the eddy fluxes are undoubtedly more important at high latitudes, they require daily data and are beyond the scope of the present study.

Thus, only MMC flux calculations (MMCHF) are presented. These fluxes (in relative units) were calculated as the product of the 70 kPa geostrophic wind and the 100-70 kPa thickness at 65° N. A monthly time series, of the sum over all longitudes, from 1946 to 1988, is shown in Figure 14. The average of this time series over all years, reveals its seasonal variation (Fig. 15), which is in general agreement with the data presented by Oort and Rasmusson (1971). Subtracting the average values in Figure 15 from the data in Figure 14 yielded an anomaly time series (Fig. 16) which was used in the subsequent analyses.

Relationships between the Arctic heat sink, North Pacific SSTs, circulation anomalies, and Canadian Prairie precipitation

The analyses presented here are by no means exhaustive, but rather only examples of what might be done with the indicated datasets.

For many of the following analyses, the Arctic heat sink data, described above, were distilled from a spatial field to a single index by simple averaging or totalling. Monthly time series of these indices were then analysed with respect to one another and in relation to sea-surface temperature and geopotential height anomalies.

Correlations between the AHS indices

Simple correlations were carried out between the five AHS indices used in this study to reveal any obvious relationships between them. The results, expressed in terms of the coefficients of determination, are shown in the following table.

	temperature	thickness	MMCHF	ice	snow	ice+snow
temperature	1.0					
thickness	0.018 ¹	1.0				
MMCHF	0.0004	0.001	1.0			
ice	0.0022	0.042 ¹	0.015 ¹	1.0		
snow	0.0415 ⁵	0.042 ⁵	0.013	0.116 ¹	1.0	
ice + snow	0.0167 ⁵	0.003	0.009	0.008	-	1.0

¹ significant at 1% level

⁵ significant at 5% level

None of the correlations is very strong. That between the ice concentration and snow cover datasets is significant at the 1% level, explaining 12% of the variance. Also significant at the 1% level are the correlations between 100-70 kPa thickness and surface temperature, and between ice concentration and the thickness and MMCHF datasets.

Correlations between AHS indices and North Pacific SST anomalies

Monthly values of each of the Arctic heat sink indices, described above, were correlated with North Pacific Ocean sea-surface temperatures, using a 5° grid (Fig. 17). The shading indicates areas having correlation coefficients higher than 0.30 ($r^2 > 0.09$). Examination of the maps reveals few similarities between the various indices. Several of them show areas of negative correlation in the central Pacific, particularly during the spring and summer months.

The temperature set (Fig. 17a) is an example of this, showing in addition some areas of positive correlation, to the south of Alaska, during the summer and autumn.

The thickness set (Fig. 17b) is characterized by a small area of negative correlation in the east during the summer, and in the central and western Pacific during the winter.

The MMC set (Fig. 17c) shows little signal during the winter, except for some positive correlation in the east and southeast from January to April. From spring through summer, there are

areas of negative correlation in the central and western Pacific.

The sea-ice set (Fig. 17d) shows a fairly persistent signal between February and May, with negative correlations in the east, and positive in the west. Up to 20% of the variance is explained in the east, and 40% in the west. The correlations appear to be still in evidence, though in a weakened state, later in the year.

The correlation coefficients for the snow set (Fig. 17e) are highest of all, but this is due to the small sample size. The areas of significance ($P = 0.05$) are similar to those on the other diagrams. In this case, there are negative correlations at low latitudes, in the central Pacific during the summer and autumn, splitting and moving to the east and west during the winter. A positive correlation area over the north central Pacific during the winter splits and moves toward the continents during the spring, coming back together the next autumn.

The lack of a strong, consistent signal makes it difficult to attribute any physical significance to these results. It is also impossible to determine, from these concurrent correlations, the direction of any "teleconnections", i.e. which is cause and which is effect. Lagged correlation studies might help to clarify this, since many of the parameters, such as SSTs, sea ice, etc., have long response times.

Correlations between AHS indices and 70 kPa geopotential anomalies

The next set of correlations was made between northern hemisphere 70 kPa geopotential height anomalies and the five Arctic heat sink indices. In this case, the data were grouped by season. Again, there appears to be little similarity between the patterns for the various indices, confirming the relatively low correlation between the indices that was noted above.

The temperature set (Fig. 18a) shows an area of strong negative correlation centered over the Greenland Sea, which persists throughout the year. It is at its greatest strength during the winter, and extends over northeastern Canada. It recedes markedly during the spring, gradually returning during the summer and autumn. A centre of positive correlation, over central Canada during the summer, shrinks slightly during the autumn, and then weakens gradually during the winter and spring.

The thickness patterns (Fig. 18b), in contrast, exhibit positive correlations over the polar region during all seasons. This extends over most of Canada during the spring, giving way to a small area of negative correlation over James Bay during the summer, which weakens during the autumn, then strengthens and expands to cover all of eastern Canada during the winter.

The MMC set (Fig. 18c) shows a positive correlation area covering the polar region, and all but southeastern North America, during the winter. A negative correlation pattern develops over the eastern Canadian Arctic in the spring, drifting southward and enlarging during summer, and moving off the east coast by fall.

The sea-ice set (Fig. 18d) shows a moderate negative correlation centre over western North America during the winter, with a weak centre of positive correlation off the east coast of Canada. By spring, negative correlation has spread over all of Canada, with positive correlation over all of the U.S.A. This situation persists through the summer, but by autumn the area of positive correlation has retreated to the northwestern U.S.A.

Again, the snow set (Fig. 18e) shows higher correlation coefficient values because of the shorter length of the data record (i.e. because of the smaller dataset, the r^2 values are less significant). Its main features are positive correlation over the polar region and negative correlation over North America. Areas of positive correlation invade the west coast of Canada, and the southeastern U.S.A. during the summer, spreading and strengthening during the autumn.

Arctic ice concentrations composited with respect to Canadian Prairie precipitation

In a search for a direct link between Arctic sea-ice concentration and Canadian Prairie precipitation, monthly sea-ice conditions were composited seasonally on the basis of overall Canadian Prairie precipitation. This is similar to the approach used by Knox and Lawford (1990) to relate circulation anomalies and Canadian Prairie precipitation. The precipitation used was the average of all stations shown in Knox and Lawford (1990). The average ice condition during the upper third (wet) months was subtracted from the average for the lowest third (dry) months and plotted in Figure 19. Positive numbers indicate more ice during dry years and/or less ice during wet years, and vice versa.

The winter season (Fig. 19a) shows strong positive values over the Labrador and Bering Seas, with slight negative values off the east coast of Greenland. In spring (Fig. 19b), there are mainly positive values over the Bering Sea, and off the coast of Newfoundland, but mainly negative ones over the Labrador and Greenland Seas.

The summer season (Fig. 19c) shows a strong pattern of positive values over all of Hudson Bay and the Barents Sea. This tends to persist in autumn (Fig. 19d), as a strong positive region develops over the Greenland Sea. Negative values develop in autumn over the Davis Strait and northern Hudson Bay.

Northern hemisphere SLPs and 70 kPa heights composited with respect to Canadian Prairie temperature and precipitation

This analysis looks for relationships between anomalies of sea-level pressure and 70 kPa height, and precipitation and surface temperature, in the five Canadian Prairie zones adapted by Knox and Lawford (1990) (Fig. 20) from the study of growing season precipitation patterns by Richman and Lamb (1987).

For the present analysis, the months of May, June, and July have been composited on the bases of temperature (two classes, warm and cool) and precipitation (three classes, dry, average and wet), and the corresponding sea-level pressure and 70 kPa height anomalies averaged for the northern hemisphere.

To justify separating the Canadian Prairies into zones, instead of treating them as a single entity, an analysis of the geographical extent of the anomalies defined above was carried out. The results are shown in the following table.

Anomalous temperature and precipitation in multiple Prairie zones						
	# of zones	1	2	3	4	5
anomaly						
dry cool		9	8	2	3	0
wet cool		9	8	3	2	0
dry warm		9	7	2	1	0
wet warm		9	4	4	1	0

Of the nine anomaly months in each category, eight affected at least two zones for the cool cases, but only four in the wet warm case. This latter is likely indicative of the highly localized nature of the convective precipitation associated with warmer airmasses during the summer months. Fully a third of the dry cool months affected four zones, while only one in nine of the dry, and wet, warm events was so widespread. There were no cases that affected all five zones. Although fewer, larger zones would have sufficed for the "cool" cases, use of the present zonation appears to be justified, particularly for the "wet warm" cases.

The composited sea-level pressure anomalies for the four temperature/precipitation categories, and five Canadian Prairie zones are shown in Figure 21. Focussing for the moment on zone 7, one may note considerable differences between the four categories, particularly between the "cool" and "warm" cases. The former are consistent with elevated, and the latter with reduced, pressures over northern Canada. There is some evidence of the North Atlantic Oscillation's positive phase in the cool cases, and the negative phase in the warm cases. "Dry" vs "wet" cases are distinguished by a stronger anomaly over western North America in the dry cases. The North Atlantic dipole is strongest in the "dry cool" and "wet warm" cases.

Moving next to a comparison of zones, it may be noted that zone 5 is the "odd man out" in the dry cool case. In other words, the

weather regime that produces anomalous dry cool weather appears to affect most of the Canadian Prairies, excepting northern Alberta, similarly. The pattern is not so clear in the other cases. Wet cool events have considerable coherence over zones 2 and 4, with zone 5 having some similarities with zone 4, and zones 6 and 7 with each other and with zone 2. Dry warm events appear to have a northwest-southeast alignment, with zones 4 and 5 having some similarities, zones 2 and 7 more, and zone 6 a loner. The warm wet (convective) regimes appear to be coherent over the southeast (zones 2 and 6), with lesser similarities between zones 6 and 7, and between zones 4 and 5.

These compare well with the "early summer" 100 kPa anomalies of Knox and Lawford (1990), based on precipitation alone.

A similar analysis was carried out with 70 kPa geopotential heights for the months of May, June and July. Results for zones 2 and 7 are shown in Figure 22. Patterns for the two zones are most similar in the dry cool case and least similar in the wet cool case. The two warm cases appear to be intermediate. Again, the cool cases are associated with the positive phase of the North Atlantic Oscillation, whereas the warm cases appear to be related to opposite phases of an east-west dipole over the North Atlantic. The two wet cases exhibit similar patterns, with a positive anomaly aligned north-south over eastern North America, and negative anomalies over the west and off the east coast. The anomalies are centered about 10° of latitude farther west in the warm case, compared with the cool. In the dry cases, there are negative anomalies over eastern North America, bounded by positive anomalies. In the dry warm case, the weak negative anomaly is centered over Lake Erie, while in the dry cool case, a much stronger anomaly is centered over northwestern Ontario. The positive anomalies are of similar strengths in the two cases, being centered over Montana in the warm case, and just off Vancouver Island in the cool case.

Once again, there is good agreement with the 50 kPa early summer results of Knox and Lawford (1990).

SUMMARY

The present work has focussed on identifying datasets for use in studying potential Arctic heat sink influences on Canadian Prairie droughts, in obtaining copies of these datasets, and in carrying out some preliminary analyses with them. Although only a few analyses have been carried out, they suggest a number of avenues of research that might lead to useful insight into surface forcing effects on Canadian Prairie droughts.

RECOMMENDATIONS

The preliminary analyses clearly demonstrate that links between the Arctic heat sink and Canadian Prairie drought are too complex to be captured in any simple way as, for example, with a single

AHS index. More detailed analyses will be required to provide a useful understanding of the connections.

With regard to an AHS index, it might be worth trying a composite of the indices presented here, in order to explain more of the month-to-month variance. However, it is likely that remote effects of the AHS (if they exist) depend not only on its overall magnitude, but on its geographical distribution as well, i.e. the location of areas of anomalous ice, snow, low temperatures.

It is also possible that positive and negative anomalies of surface forcing conditions may not have symmetrical effects. In view of this possibility, it would be wise to treat them separately in a correlation, or to use some other analysis method.

Some stratification of the data by season and zone has been included in the present analysis. This could be extended and improved considerably, and would likely lead to more useful results.

The use of time offsets, or lagging, in the analyses, would be more appropriate when looking for evidence of cause-effect relationships because of the long response times of some components of the ocean-atmosphere system.

Correlations between the spatial patterns of the surface forcing anomalies and spatial patterns of pressure, height, ocean SSTs, soil moisture, precipitation, etc. using canonical correlation analysis might yield useful relationships.

Other data, that have not been used in the present study, but which may have potential usefulness, are: soil moisture data, cloud data, and gridded North American continent data. The first type of data are useful in specifying historical drought periods, and in testing water-balance models. Although there have been many soil moisture observations taken in the Canadian Prairies over the years, they are not readily available, and usually difficult to interpret and make use of. Cloud data, from human observations are often not very reliable, particularly at night and during the Arctic winter. It is also risky trying to extrapolate a few point cloud observations to a large geographical region. Recent satellite data hold more promise. A report by Hanzis and O'Brien (1989) summarizes the climatology of cloud cover over North America for the period 1980-1987. Although the present dataset is rather brief for statistical analysis, it will become increasingly useful as the length of record increases. The development of an integrated North American climatological dataset, incorporating data from Canada, the United States and Mexico will be of great benefit in carrying out climatological analyses on a continental scale. Some progress has been made in this direction, and hopefully such efforts will not be aborted.

ACKNOWLEDGEMENTS

I wish to thank Rick Lawford of the Hydrometeorological Research Division for proposing the theme of this study, and for securing some financial support for it. I am also grateful to the University of Saskatchewan for granting a year's sabbatical leave, and to the Scripps Institution of Oceanography for giving me the opportunity to spend it with their Climate Research Division. Particular thanks are due to Dan Cayan at Scripps for invaluable advice and assistance.

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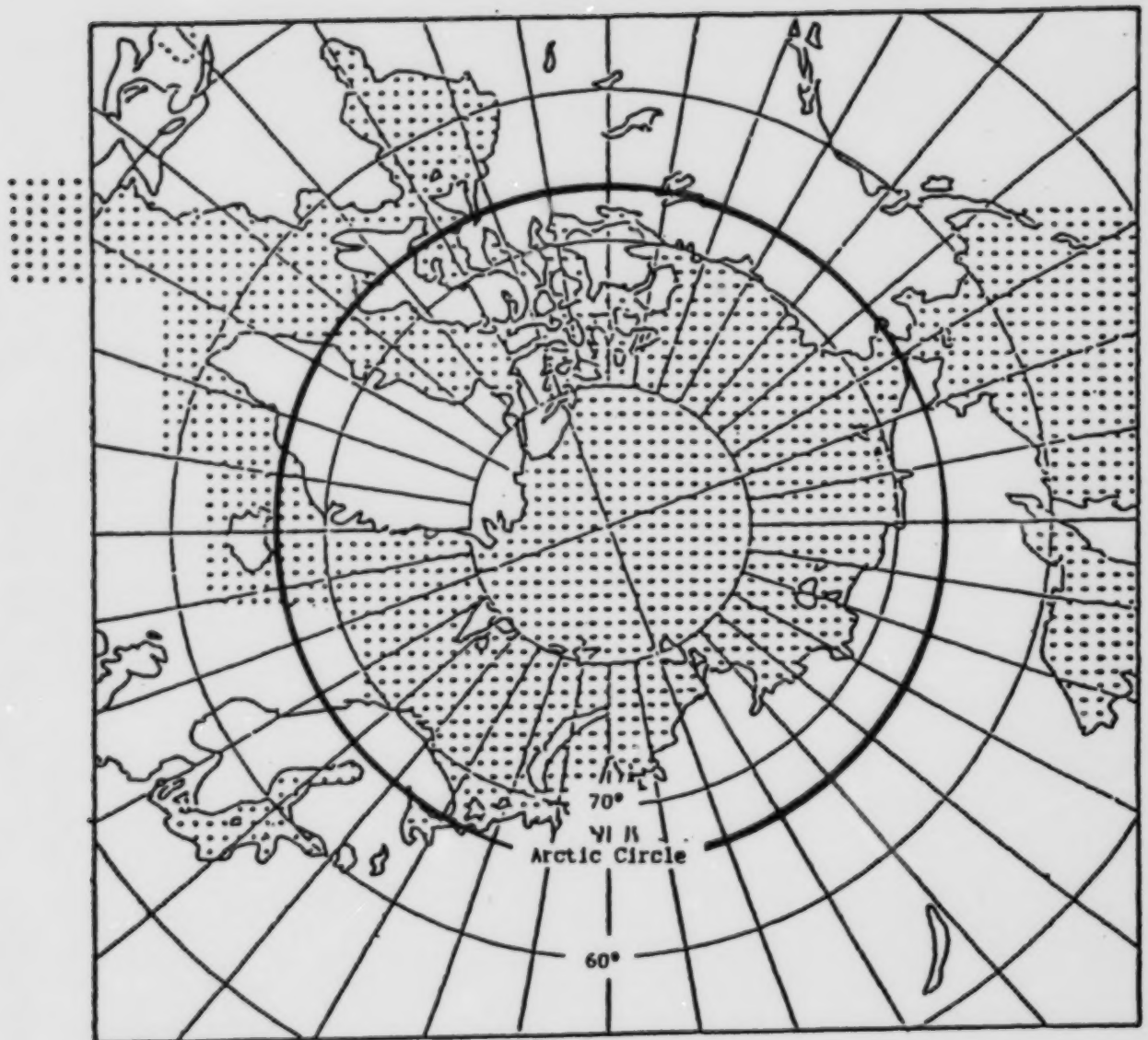


Fig. 1. The Arctic extent, showing grid points of sea-ice data availability (Walsh, personal communication).

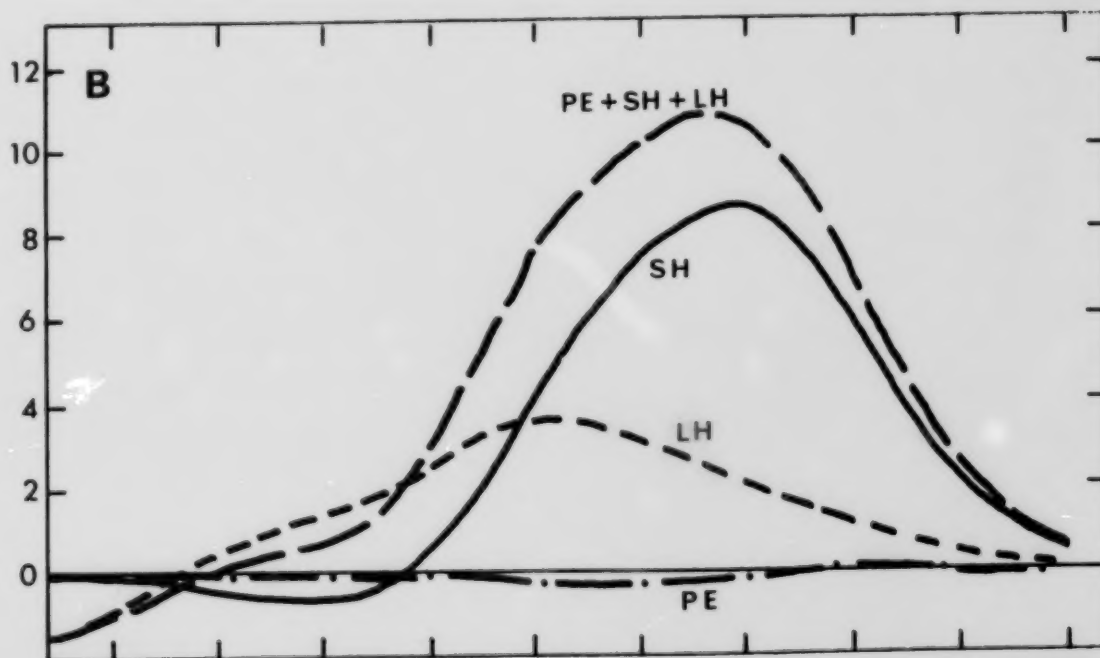
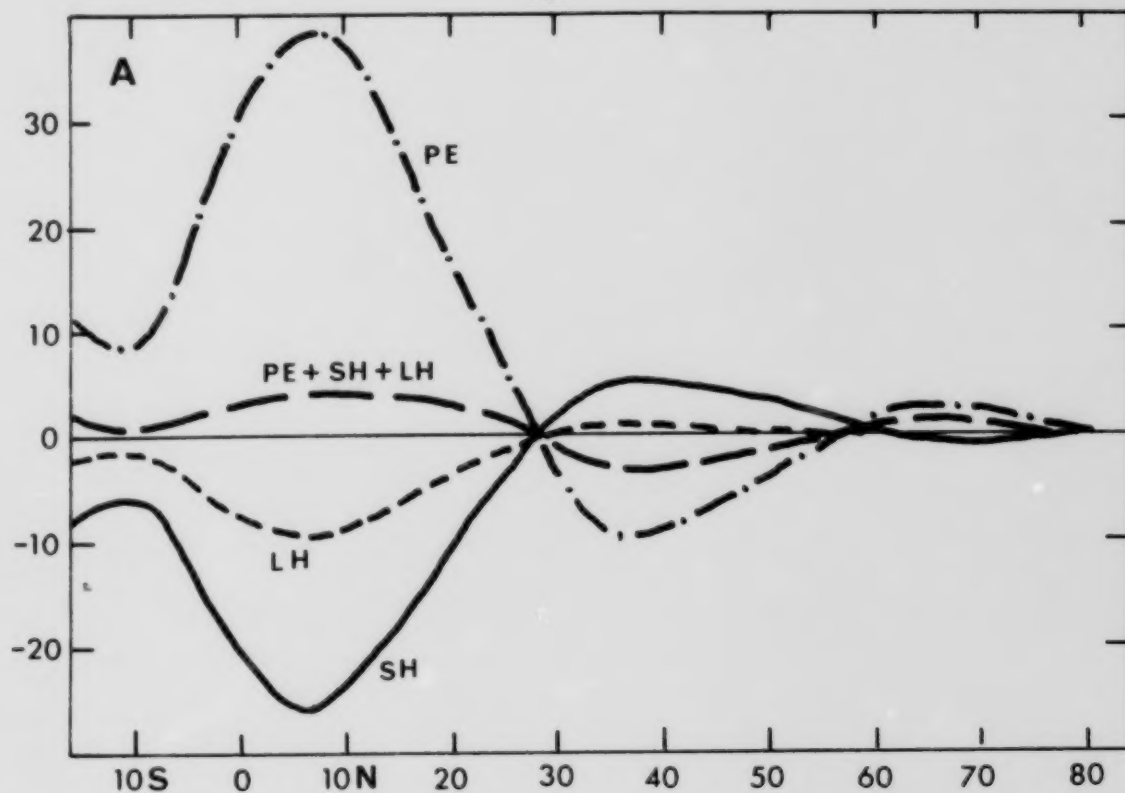


Fig. 2. Mean and eddy fluxes of potential energy (PE), sensible heat (SH), latent heat (LH), and total energy from 10°S to 80°N for the month of January (Oort and Rasmusson, 1970). A. Mean fluxes and B. Eddy fluxes. Units are 10^{19} cal/day.

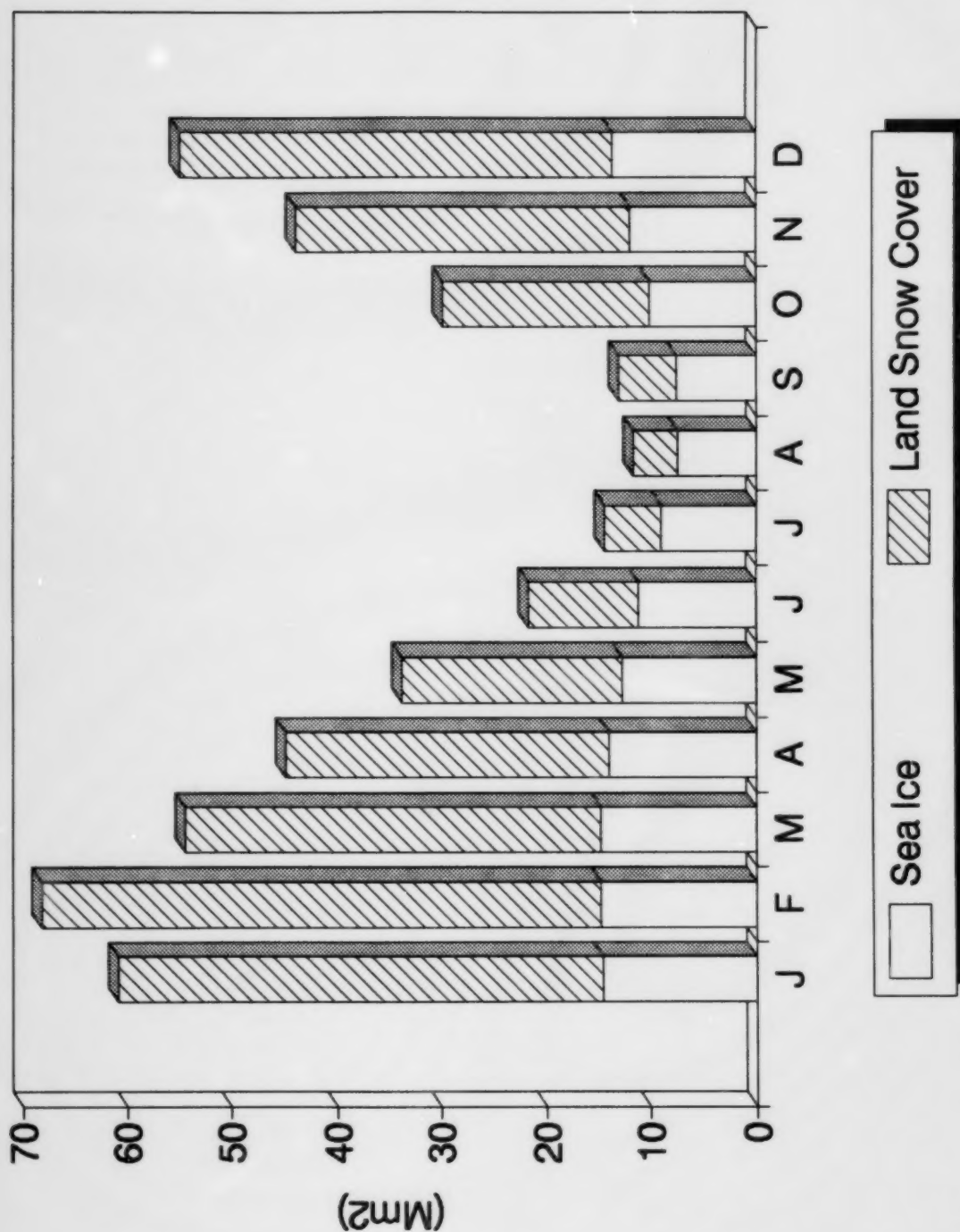


Fig. 3. Seasonal variation of northern hemisphere snow and ice cover (from Dewey and Heim, 1982, and Walsh, 1978).

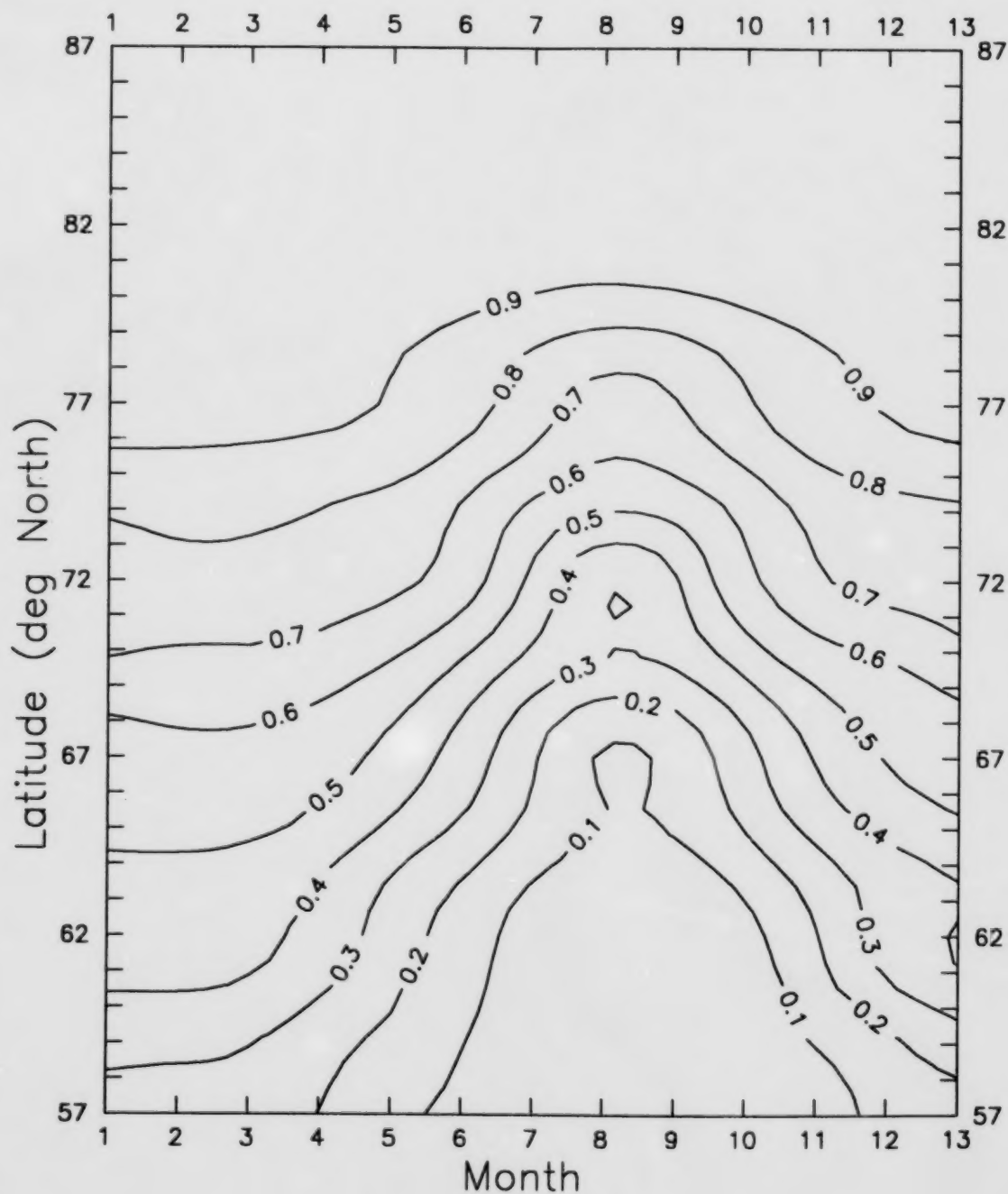


Fig. 4. Seasonal and latitudinal variation of northern hemisphere sea ice cover in fraction of sea surface (Walsh, 1978).

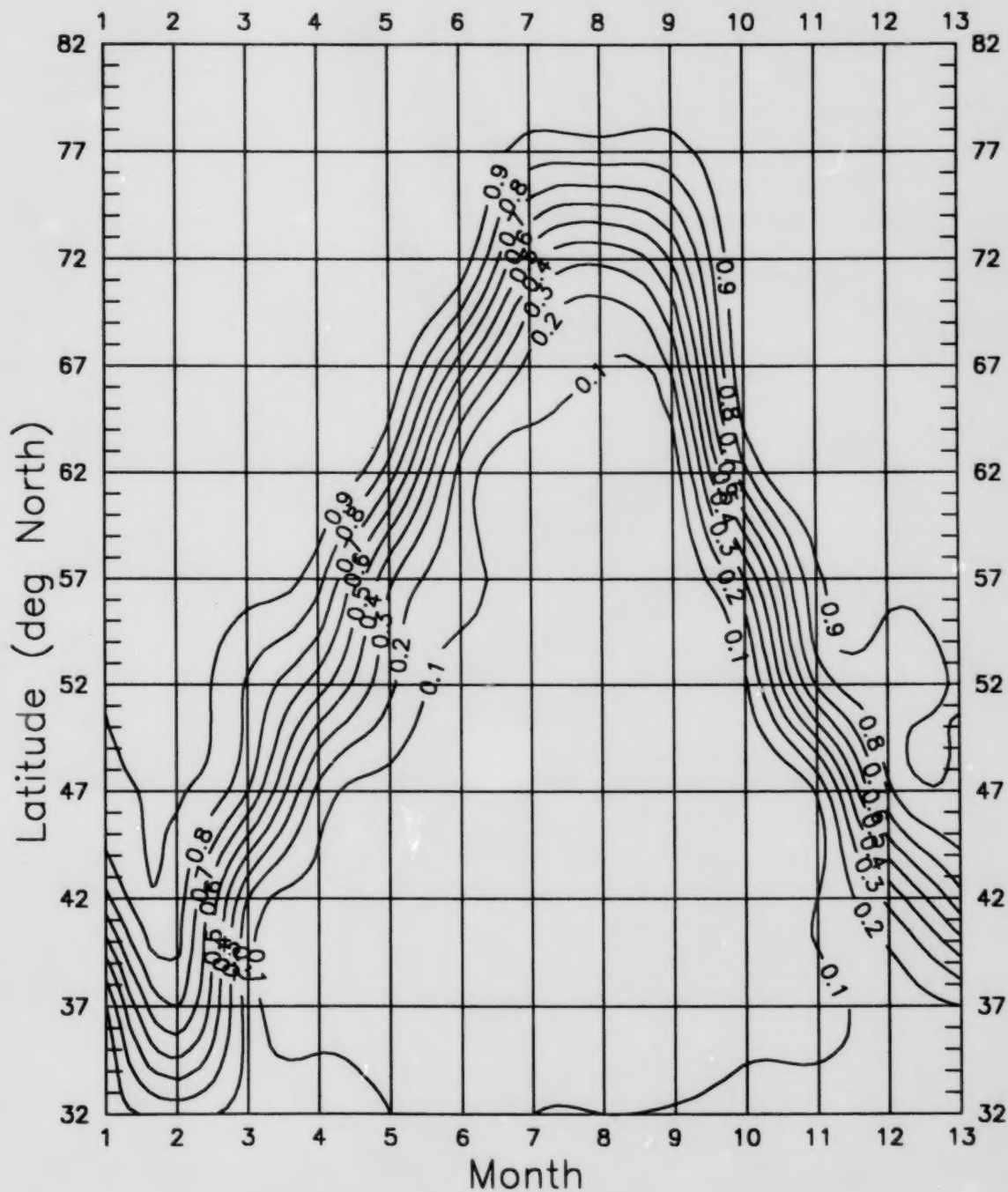


Fig. 5. Seasonal and latitudinal variation of northern hemisphere snow cover in fraction of land surface (Dewey and Heim, 1982).

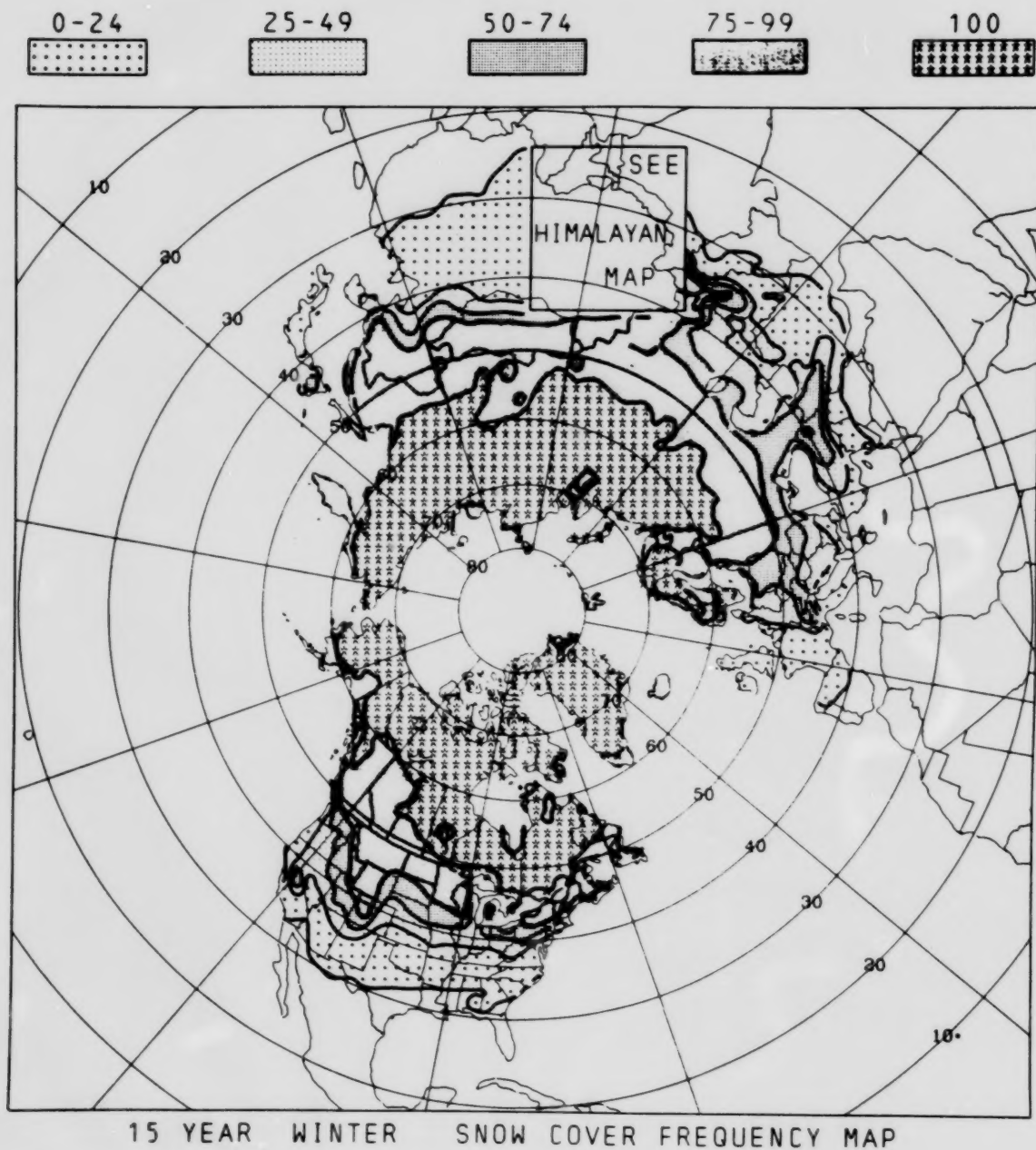


Fig. 6. Northern hemisphere winter snow cover frequency in percent (Matson et al., 1986). See original reference for separate Himalayan map.

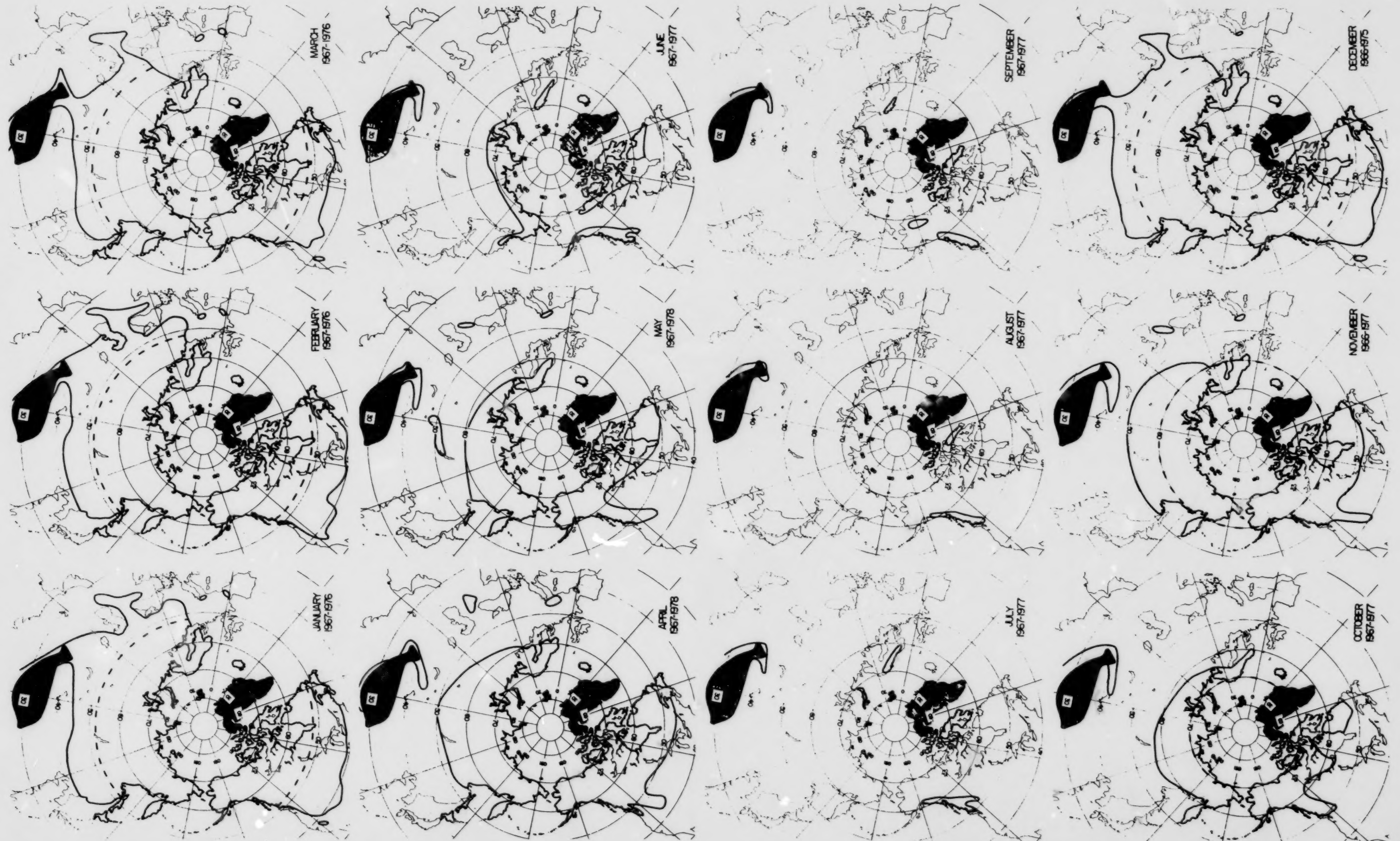


Fig. 7. Northern hemisphere monthly mean snow cover, 1967-1977 (Robock, 1980). Heavily shaded areas indicate permanent snow cover.

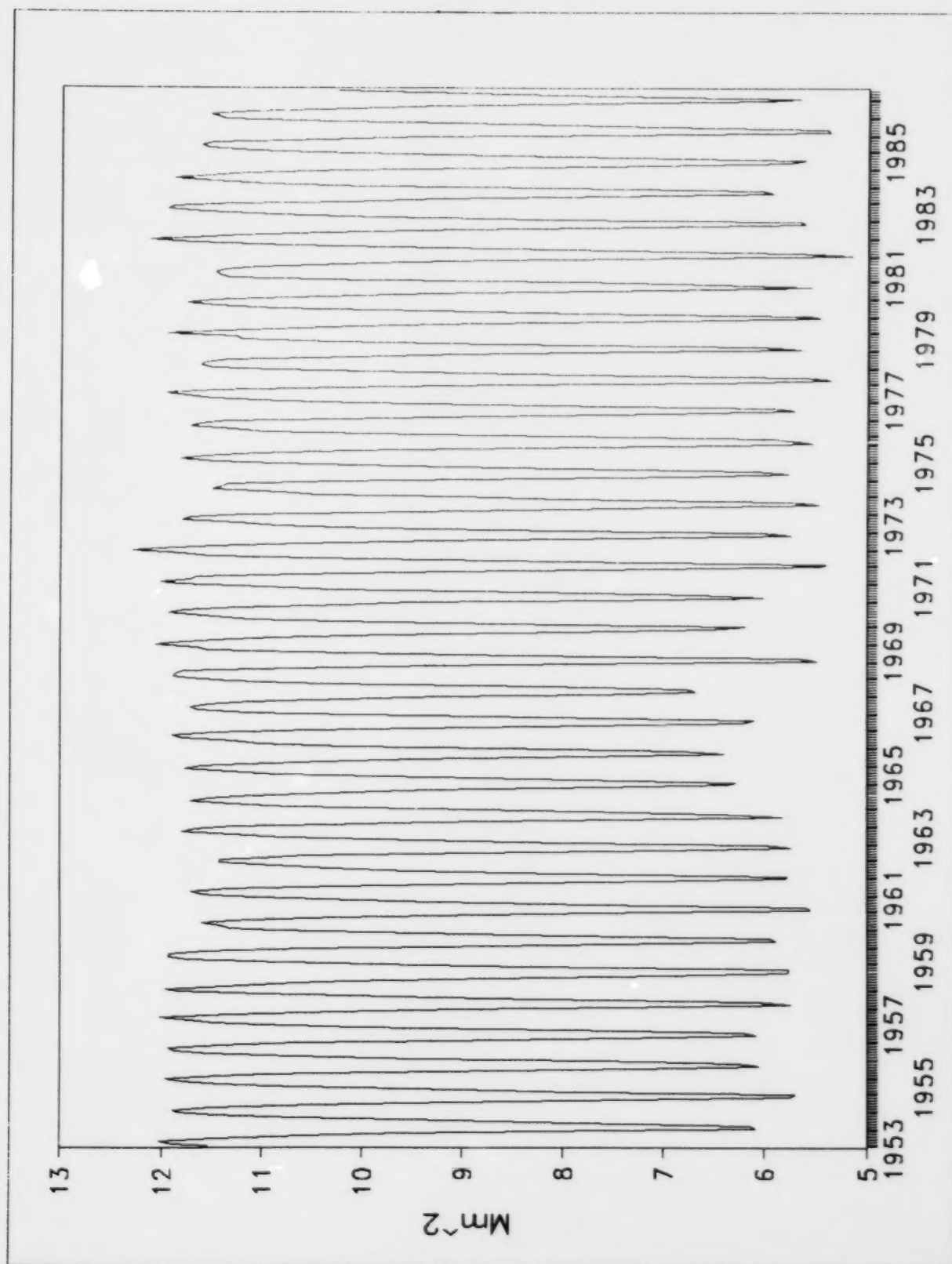


Fig. 8. 1953-1986 time series of monthly Arctic ice concentrations (Walsh, 1978).

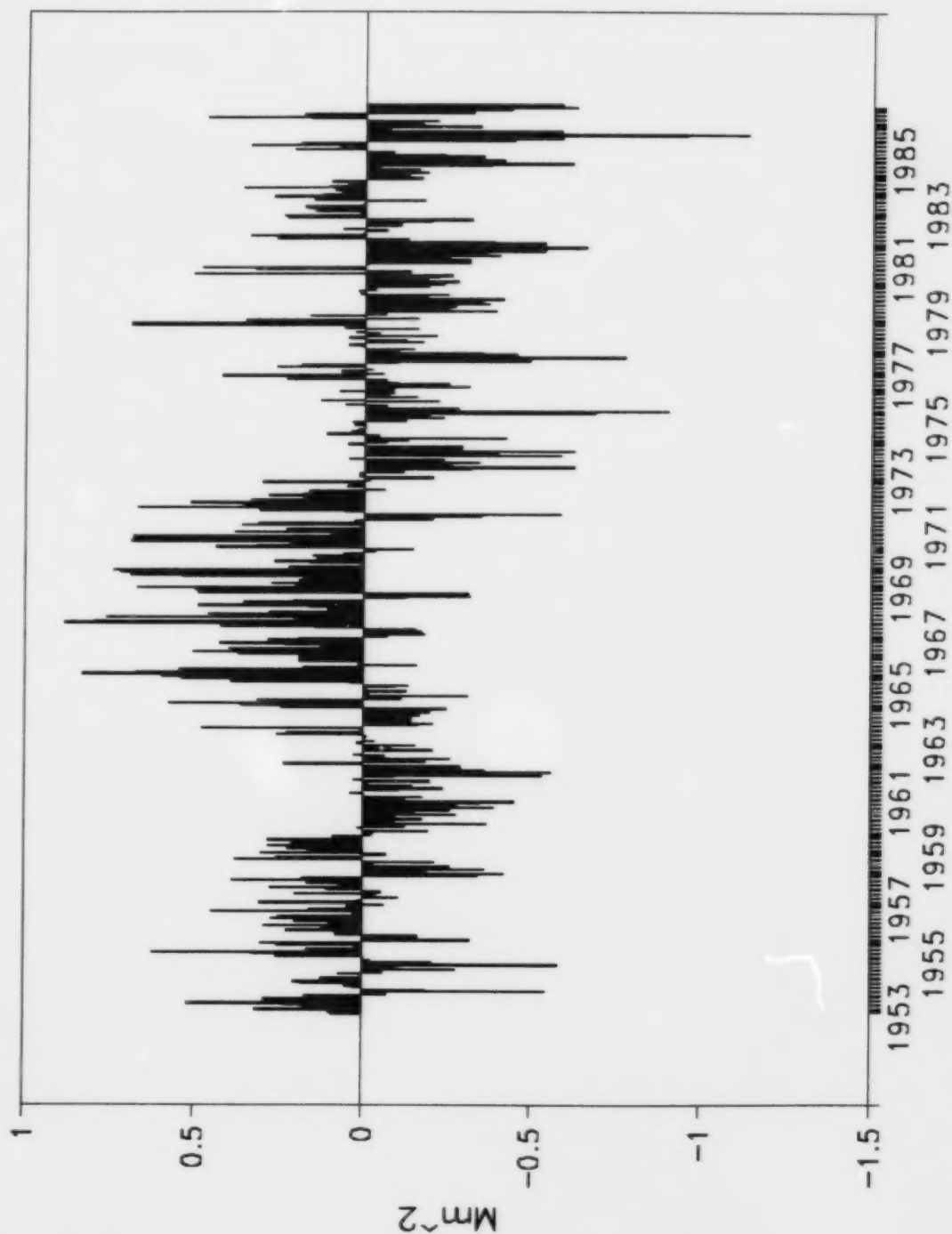


Fig. 9. 1953-1986 time series of monthly Arctic ice concentration anomalies (Walsh, 1978).

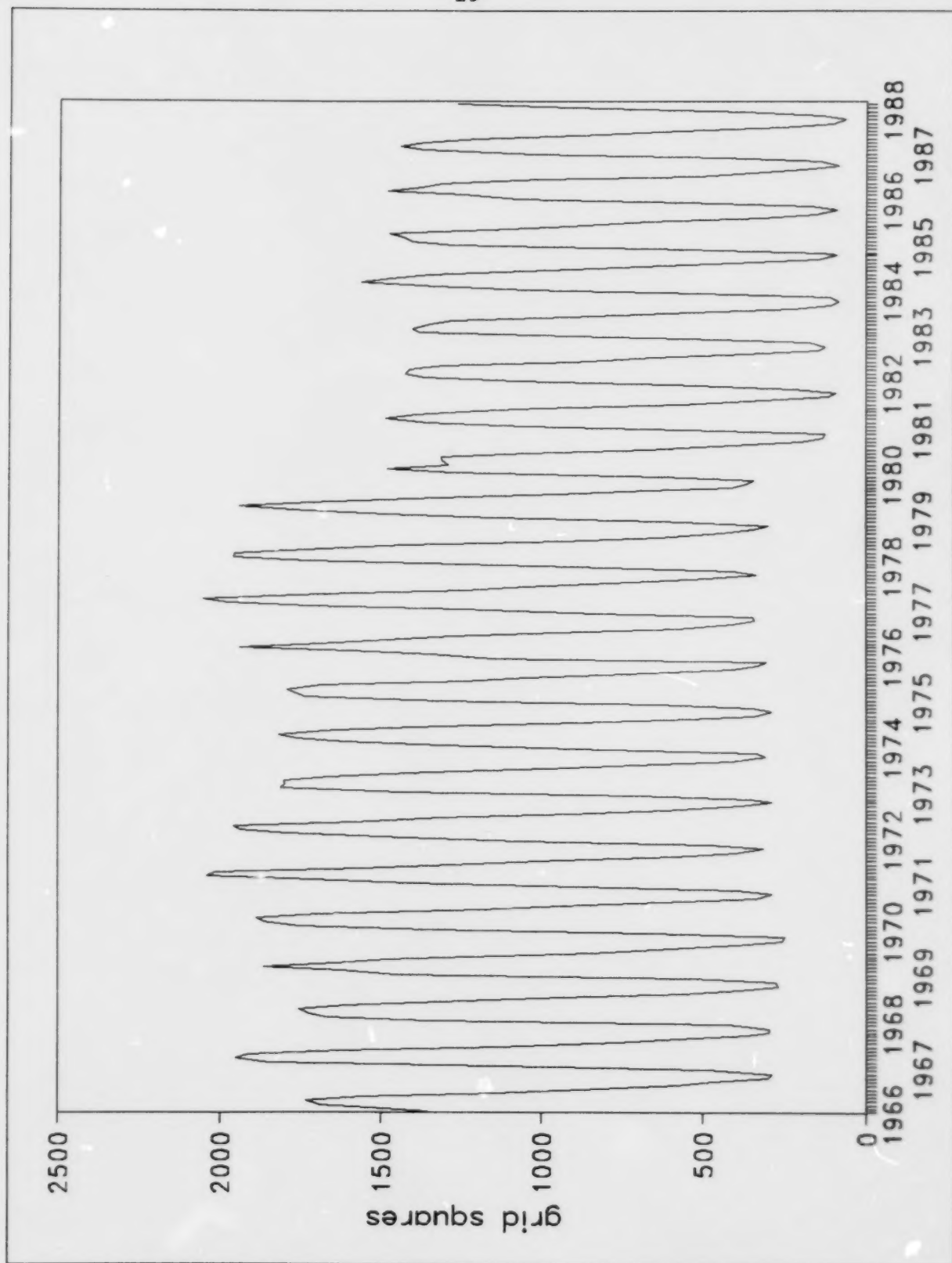


Fig. 10. 1966-1988 NOAA/NESDIS monthly Arctic snow cover (Dewey and Heim, 1982). Plotted data are snow plus ice until the end of 1980, then snow only.

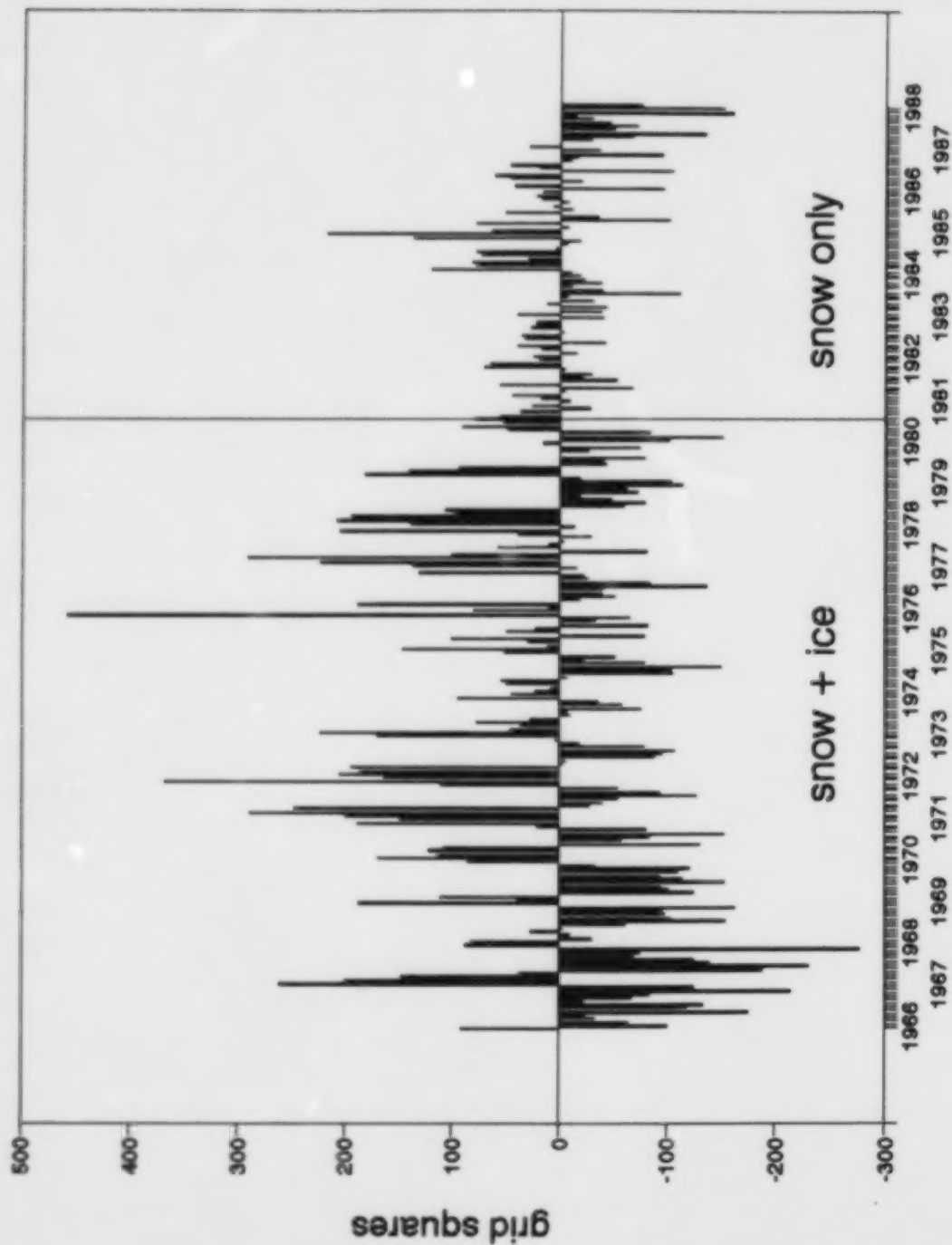


Fig. 11. 1966-1988 NOAA/NESDIS monthly Arctic snow cover anomaly (Dewey and Heim, 1982). Plotted data are snow plus ice until the end of 1980, then snow only.

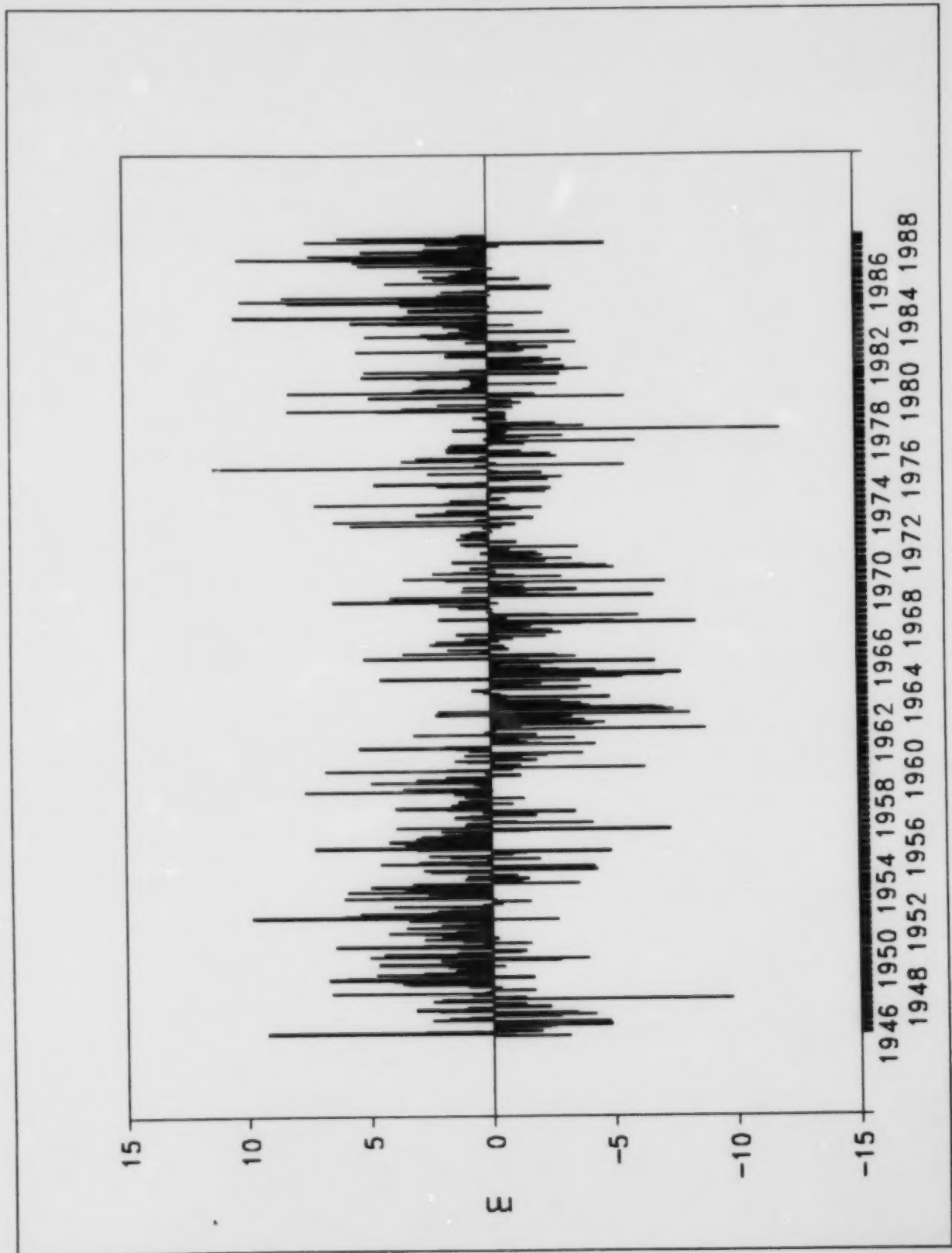


Fig. 12. Monthly Arctic 100-70 kPa thickness anomalies (average of latitudes 65°N to 80°N).

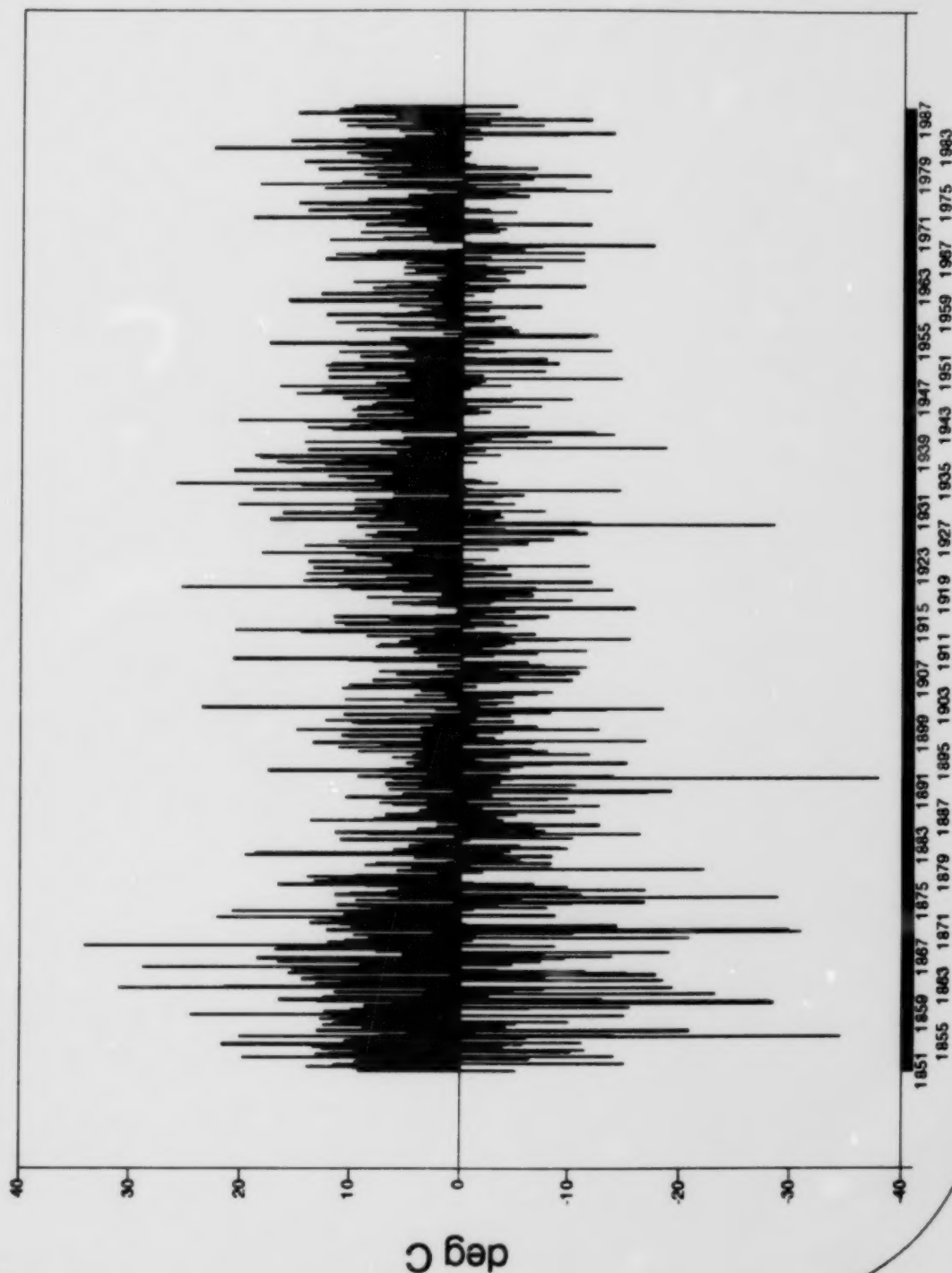


Fig. 13. Monthly Arctic temperature departures from the 1951-70 mean. These are averages of all grid values between 65°N and the pole. Note that positive departures exceed negative.

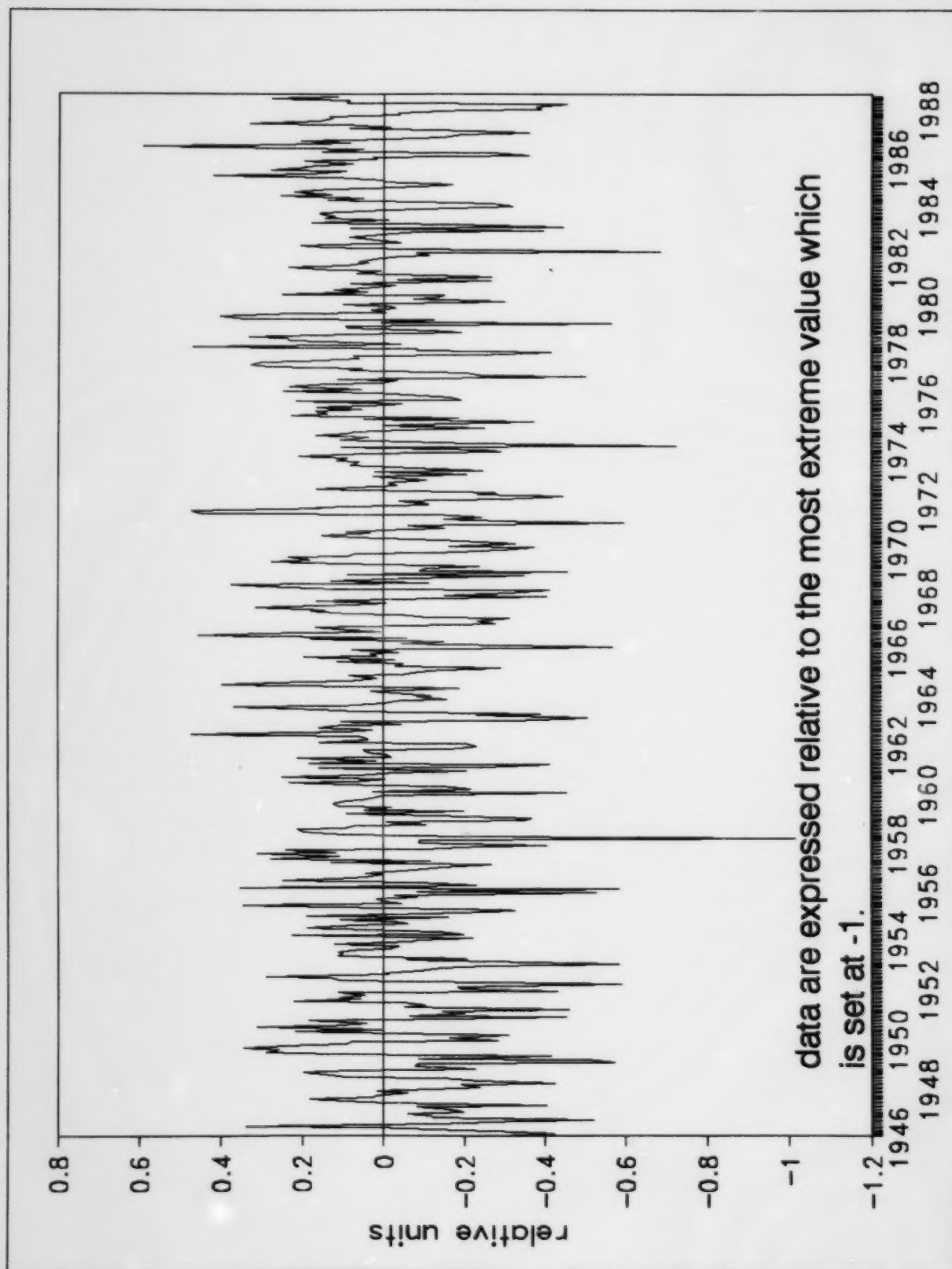


Fig. 14. Monthly values of meridional circulation heat flux at 65°N.

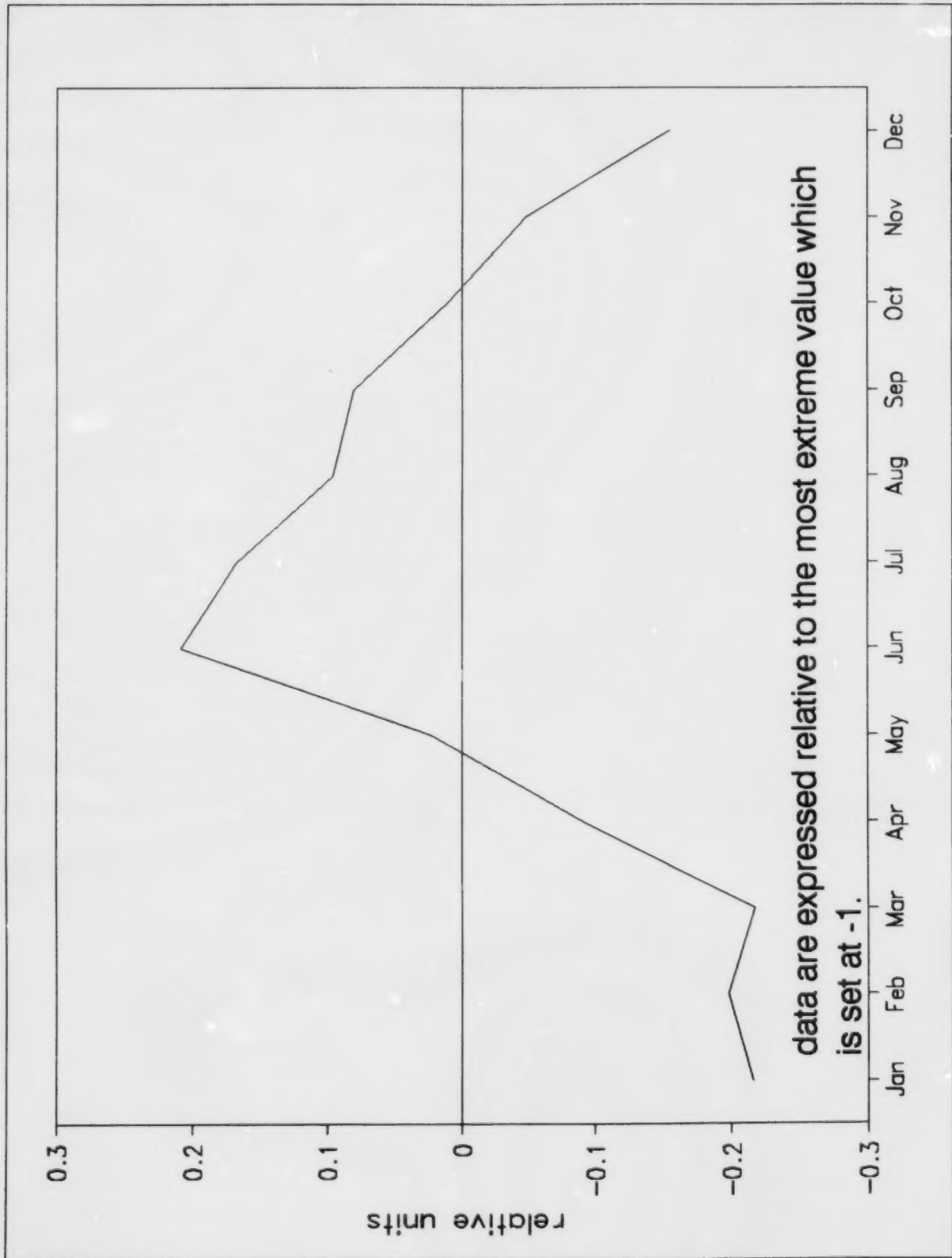


Fig. 15. Long-term average of monthly meridional circulation heat flux at 65°N.

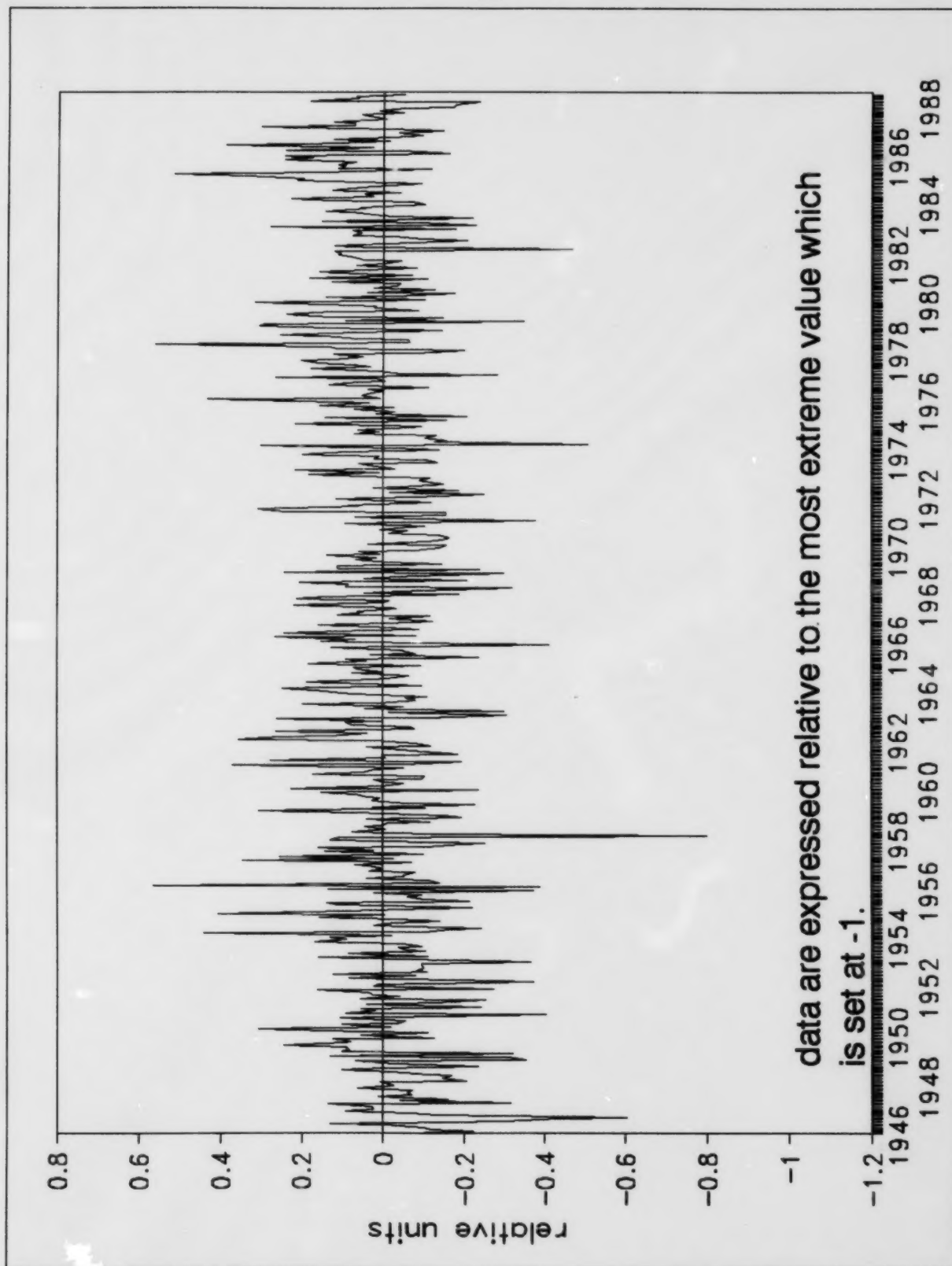


Fig. 16. Monthly anomalies of meridional circulation heat flux at 65°N.

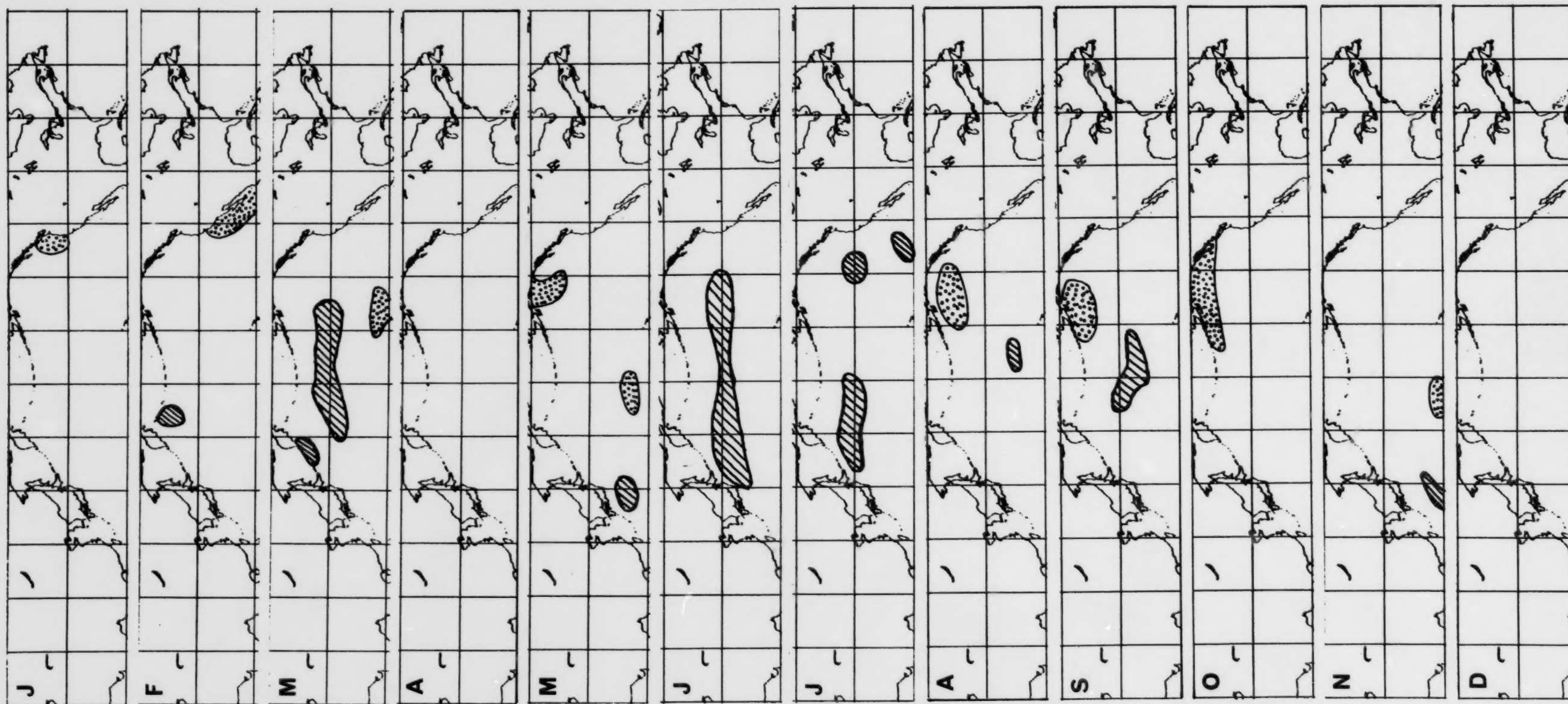


Fig. 17a. Correlations between North Pacific SST anomalies and Arctic temperature. Hatched shading indicates areas with negative correlation coefficients in excess of 0.3. Dotted shading is the equivalent for positive correlation. These are statistically significant at the 5% level.

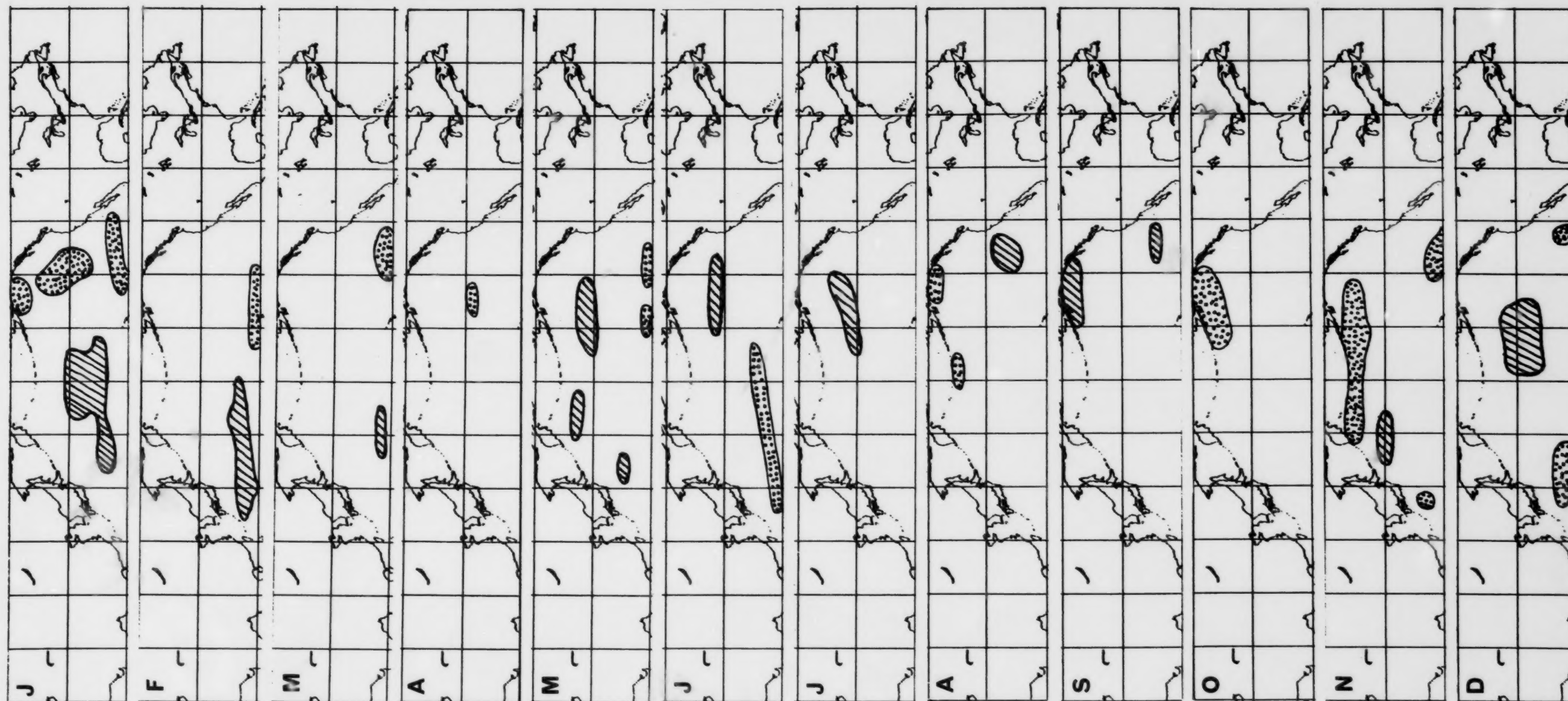


Fig. 17b. Correlations between North Pacific SST anomalies and Arctic 100-70 kPa thickness. Hatched shading indicates areas with negative correlation coefficients in excess of 0.3. Dotted shading is the equivalent for positive correlation. These are statistically significant at the 5% level.

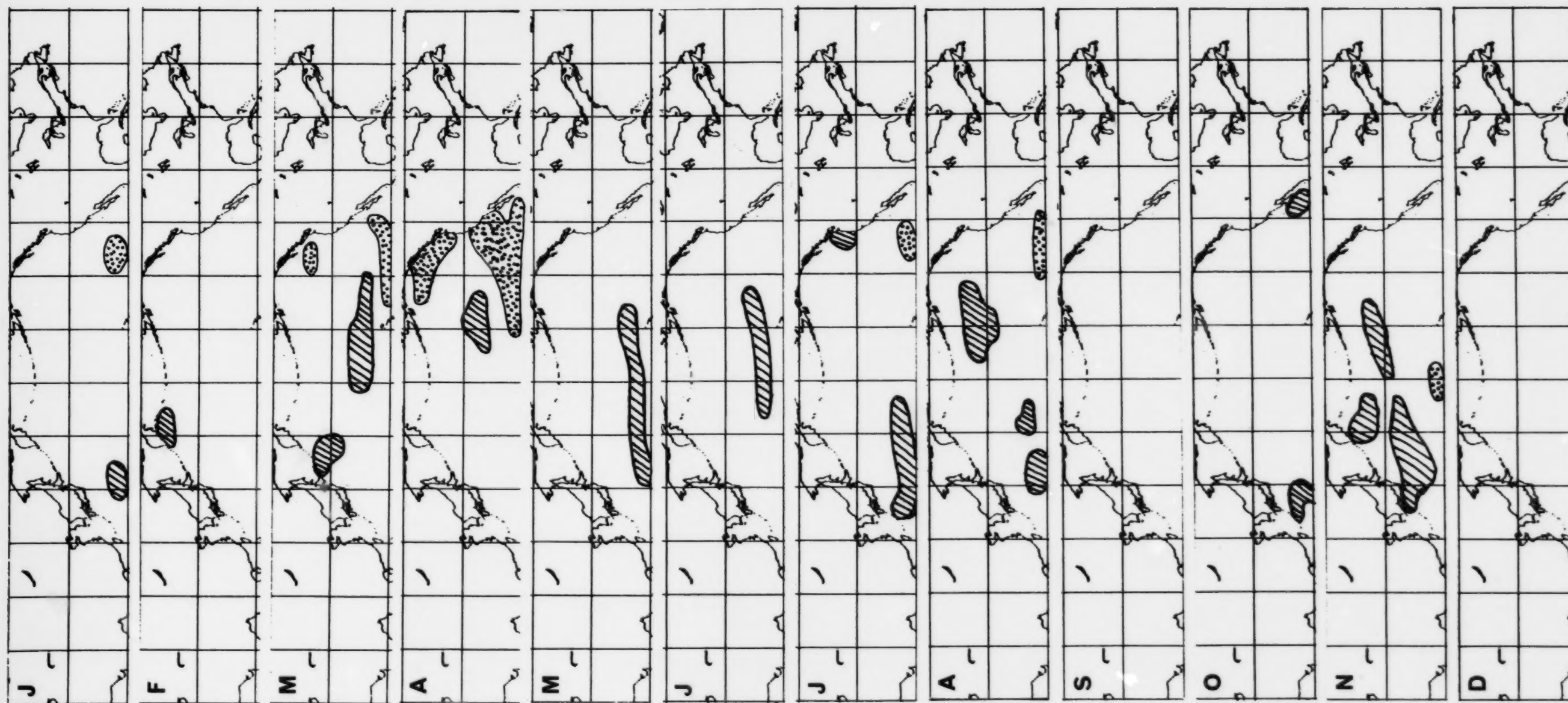


Fig. 17c. Correlations between North Pacific SST anomalies and Arctic mean meridional circulation heat flux. Hatched shading indicates areas with negative correlation coefficients in excess of 0.3. Dotted shading is the equivalent for positive correlation. These are statistically significant at the 5% level.

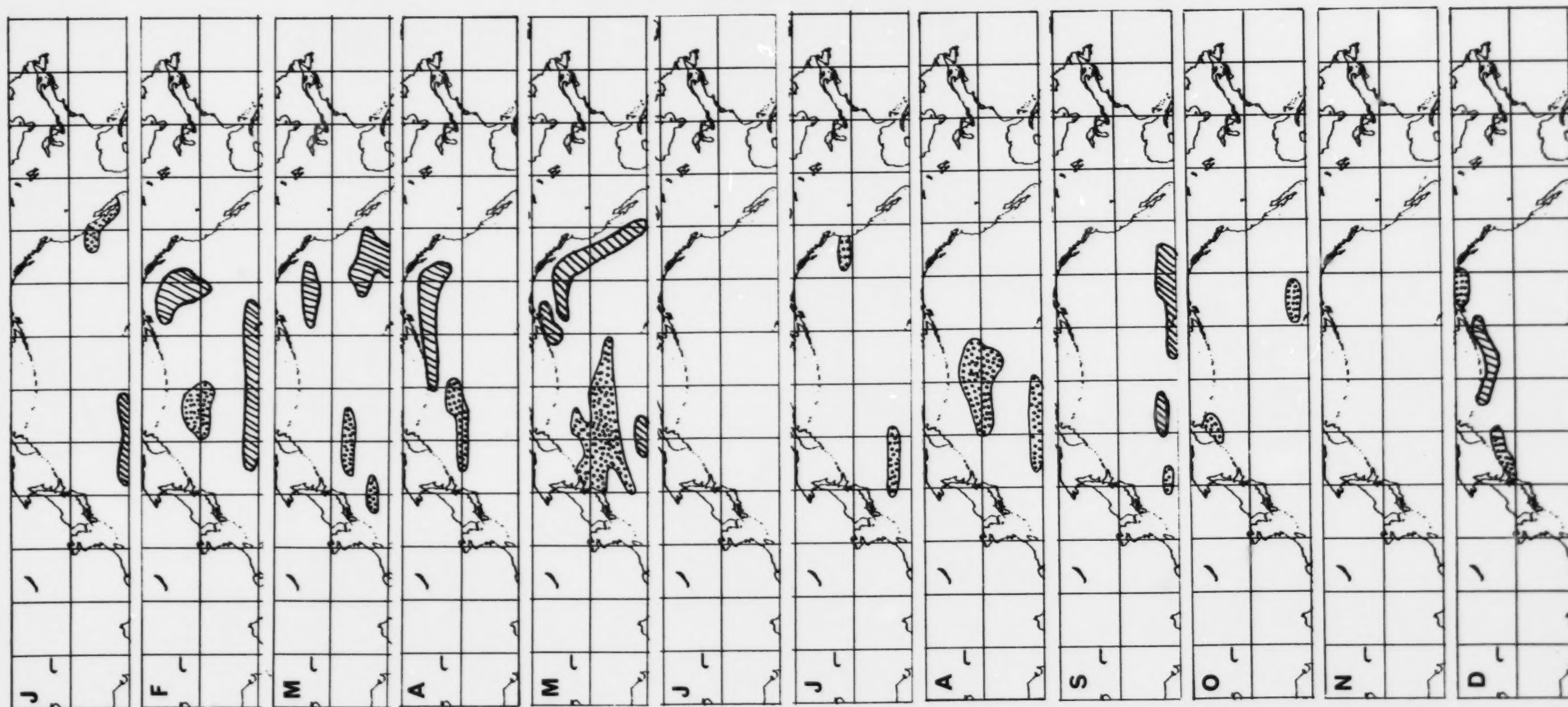


Fig. 17d. Correlations between North Pacific SST anomalies and Arctic sea-ice concentration. Hatched shading indicates areas with negative correlation coefficients in excess of 0.34. Dotted shading is the equivalent for positive correlation. These are statistically significant at the 5% level.

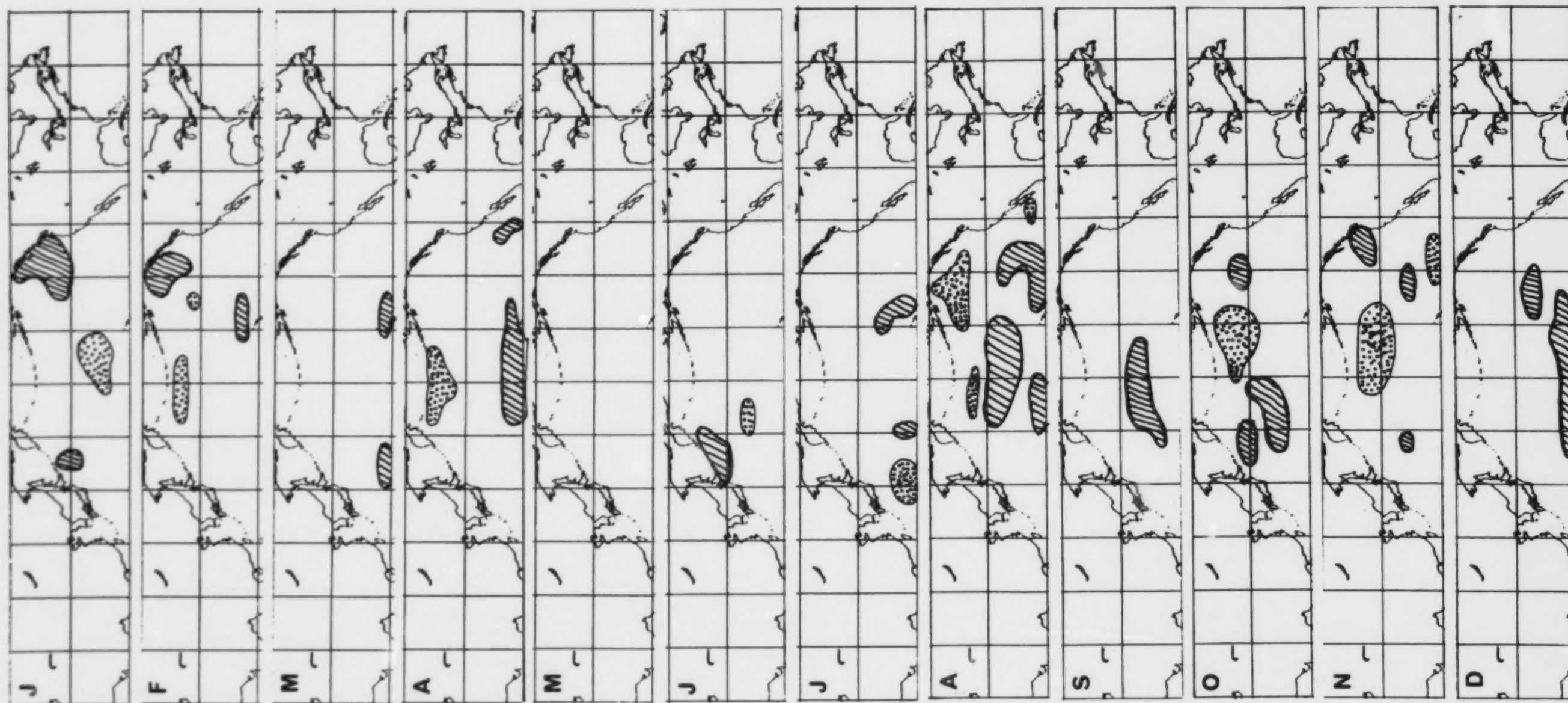


Fig. 17e. Correlations between North Pacific SST anomalies and Arctic snow cover. Hatched shading indicates areas with negative correlation coefficients in excess of 0.64. Dotted shading is the equivalent for positive correlation. These are statistically significant at the 5% level.

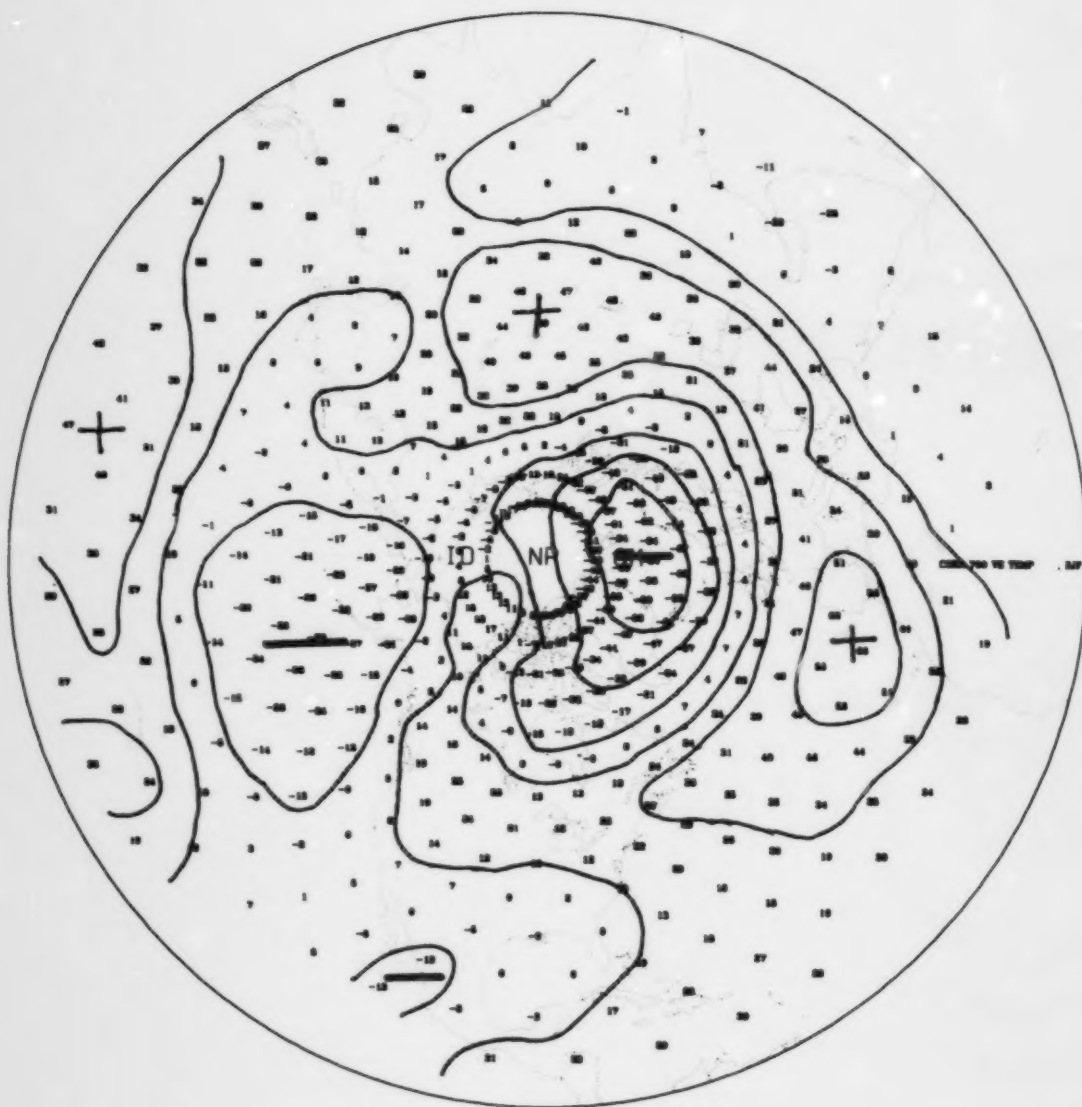


Fig. 18a. Correlation coefficients ($\times 100$) of northern hemisphere 70 kPa heights with Arctic temperature. 1. DJF. Values in excess of 30 are significant at the 5% level.

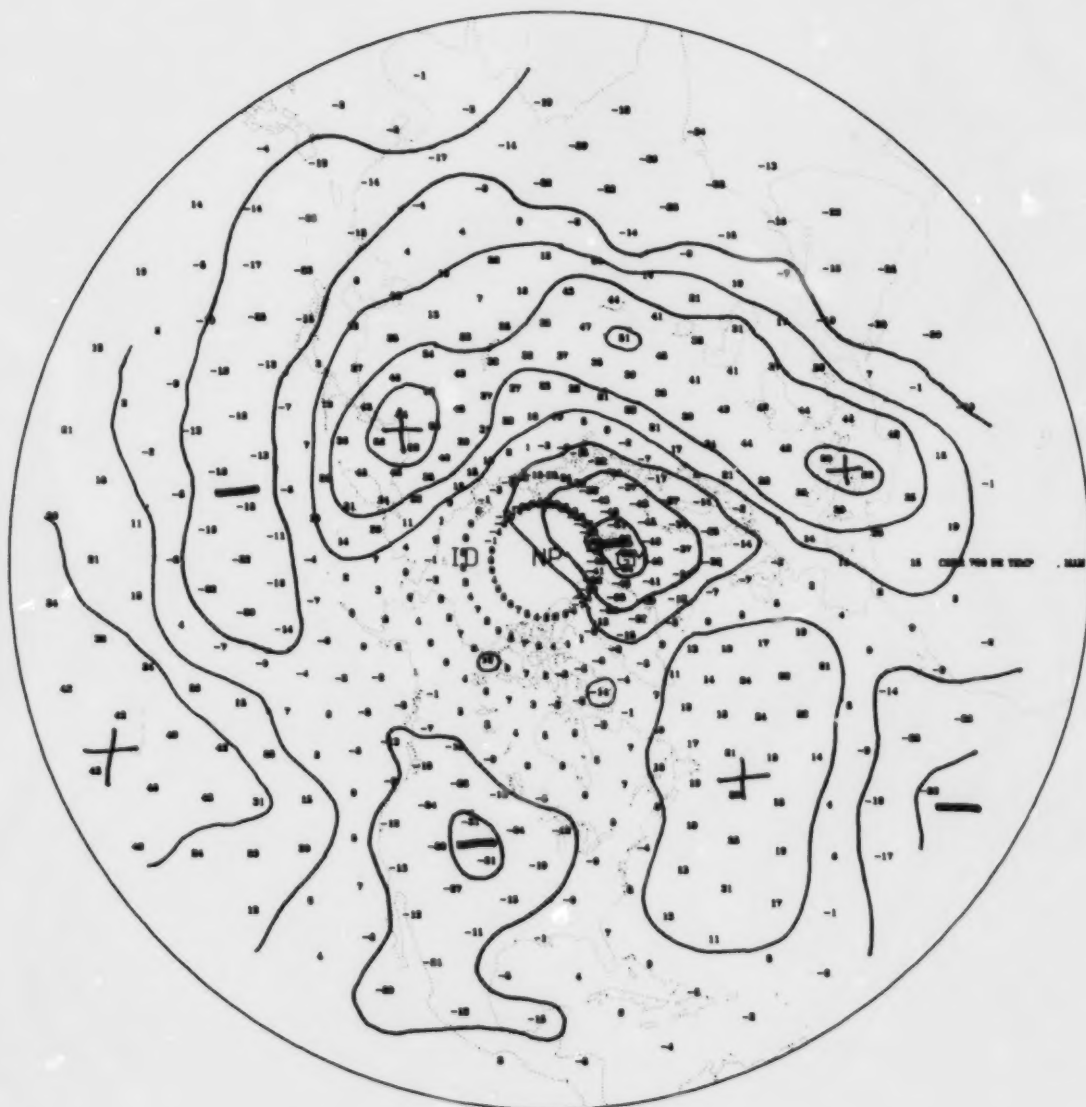


Fig. 18a. Correlation coefficients (x100) of northern hemisphere 70 kPa heights with Arctic temperature. ii. MAM. Values in excess of 30 are significant at the 5% level.

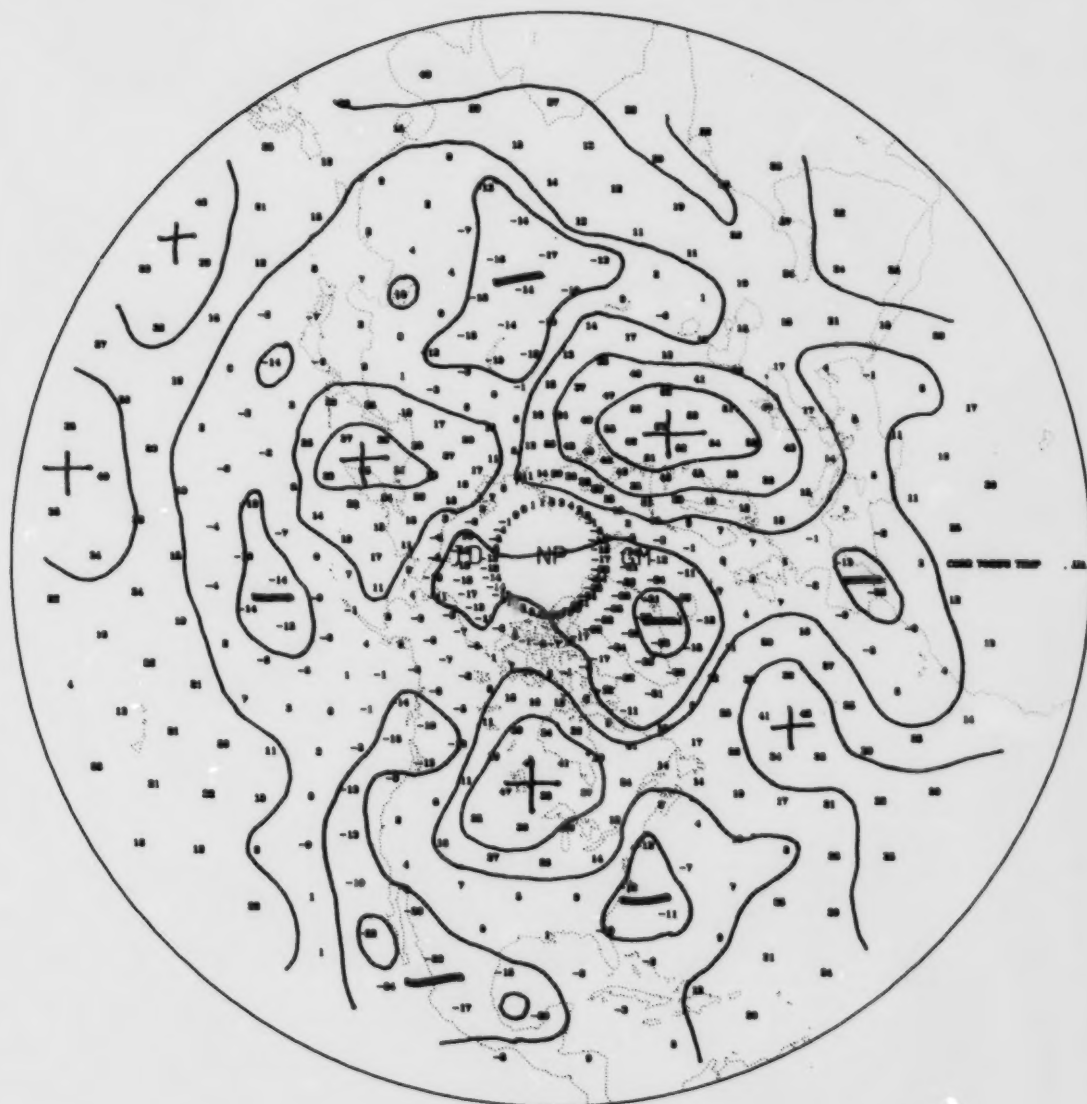


Fig. 18a. Correlation coefficients (x100) of northern hemisphere 70 kPa heights with Arctic temperature. iii. JJA. Values in excess of 30 are significant at the 5% level.

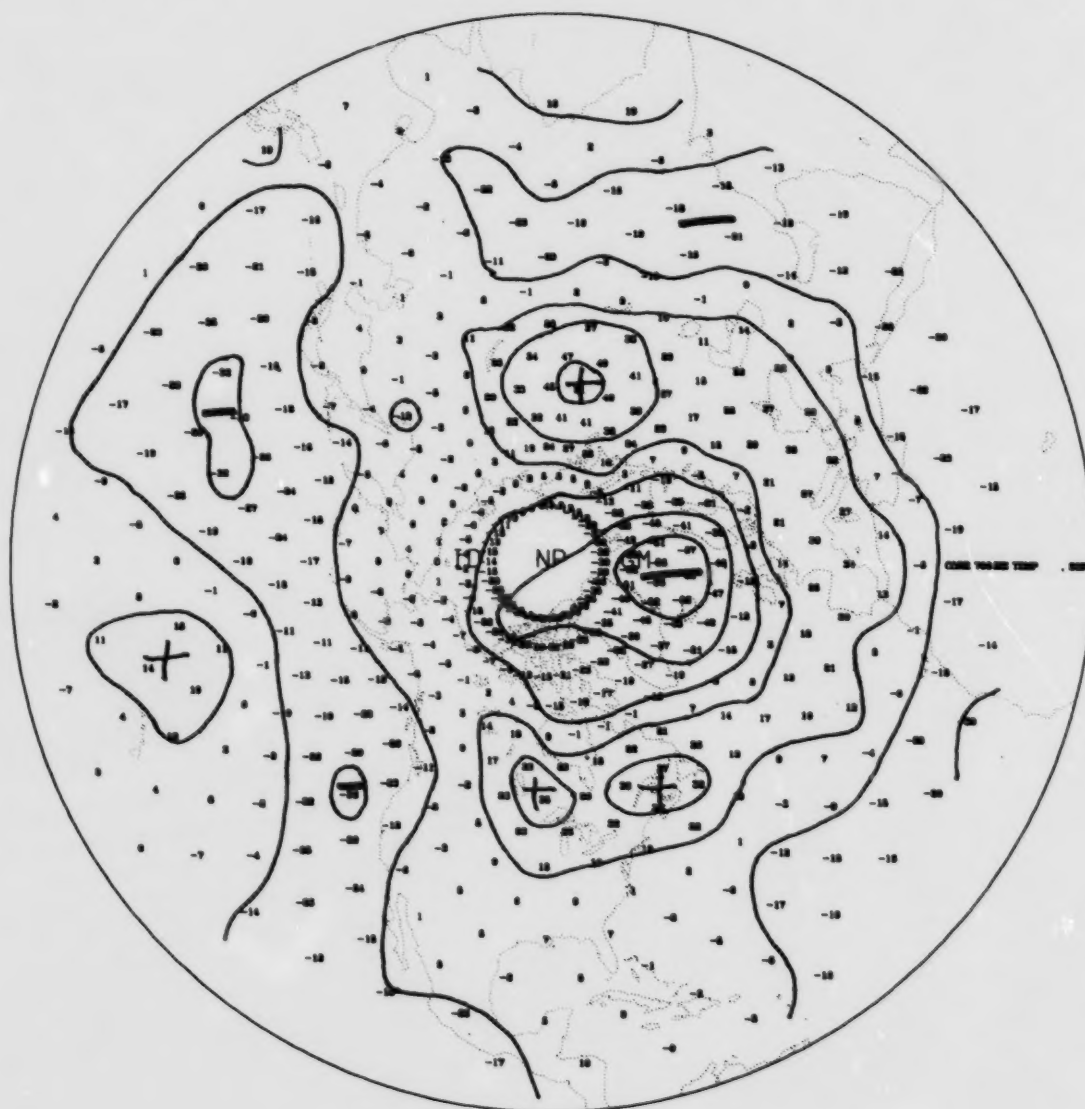


Fig. 18a. Correlation coefficients (x100) of northern hemisphere 70 kPa heights with Arctic temperature. iv. SON. Values in excess of 30 are significant at the 5% level.

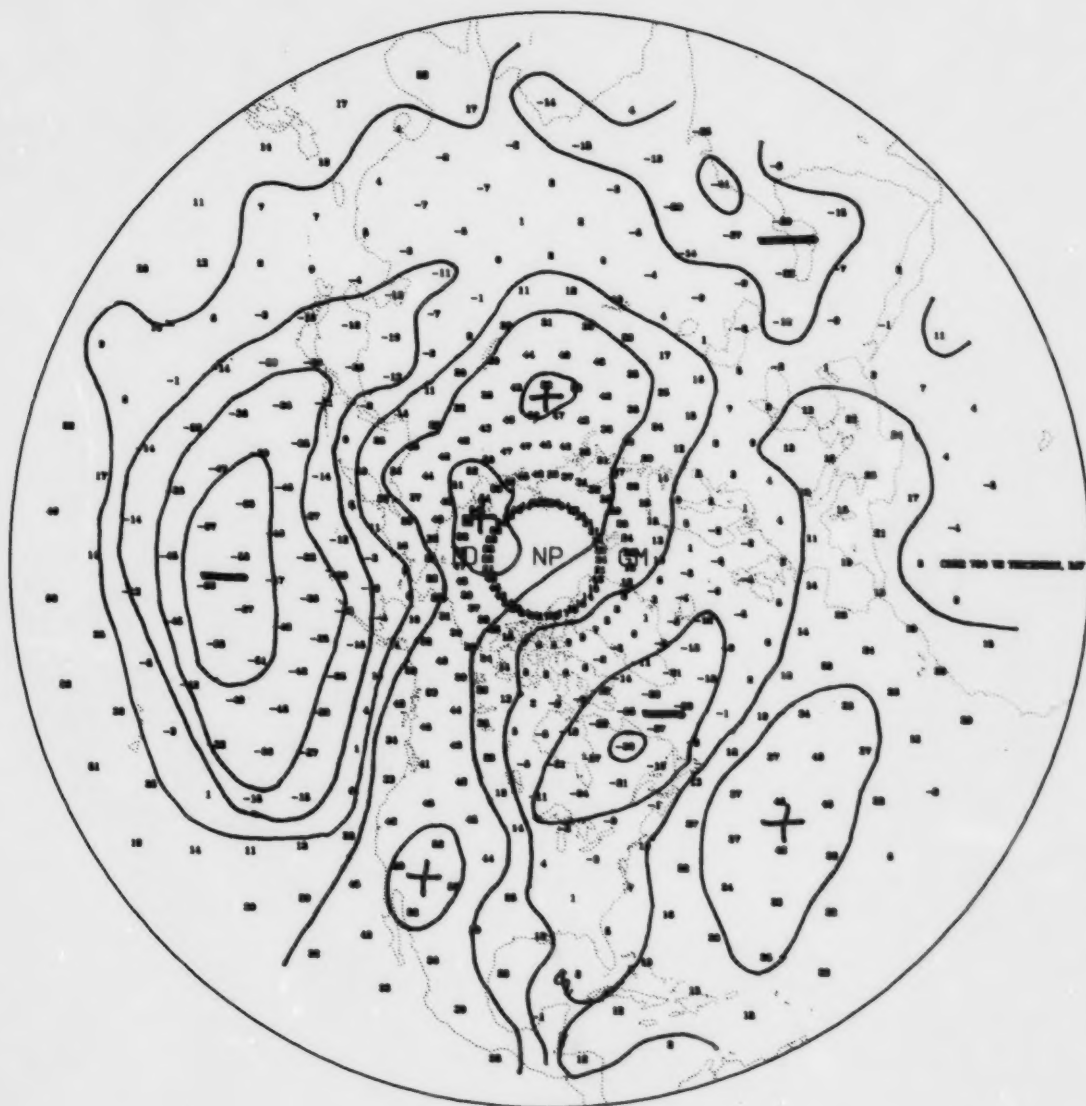


Fig. 18b. Correlation coefficients (x100) of northern hemisphere 70 kPa heights with Arctic 100-70 kPa thickness. 1. DJF. Values in excess of 30 are significant at the 5% level.

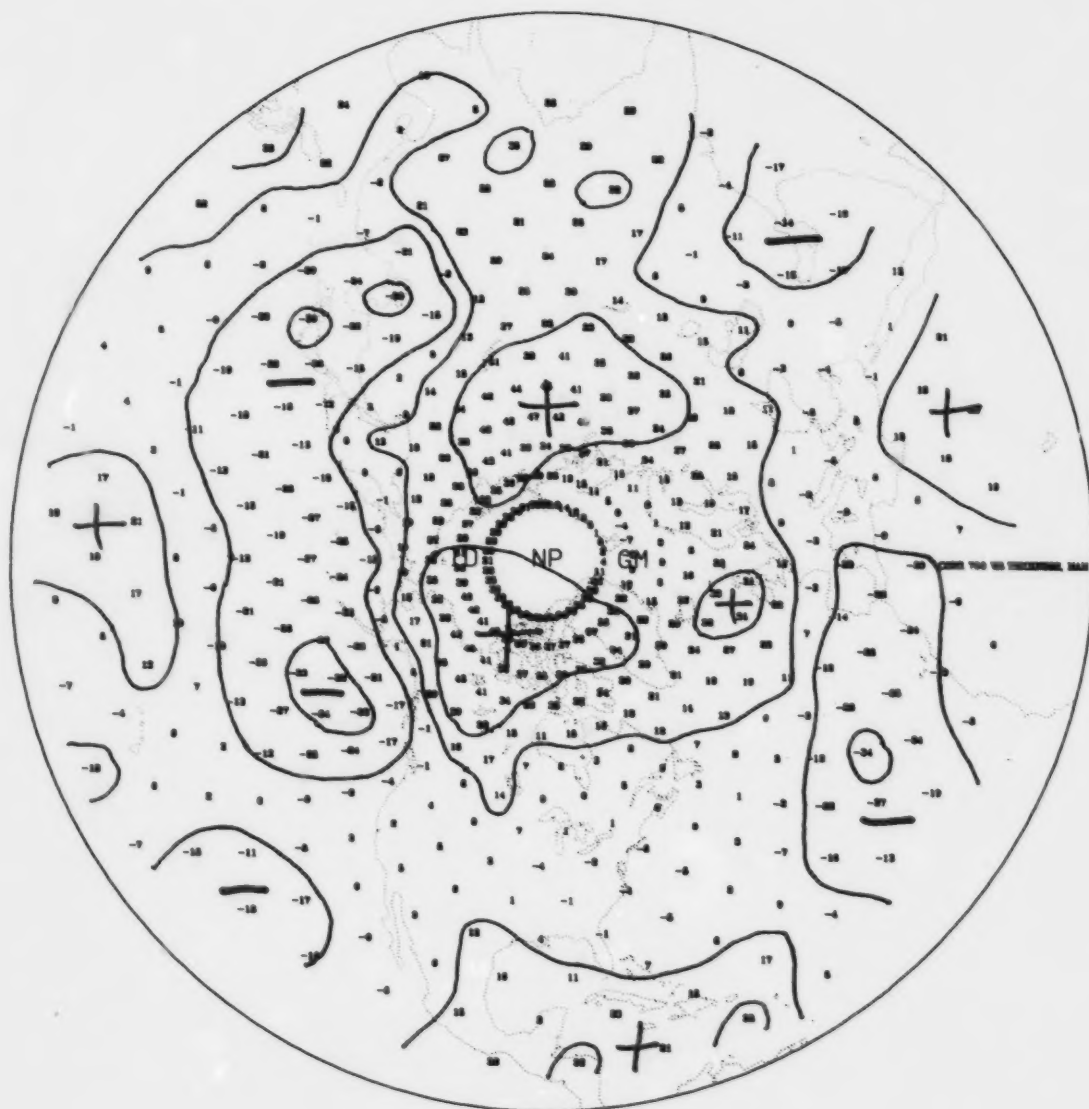


Fig. 18b. Correlation coefficients (x100) of northern hemisphere 70 kPa heights with Arctic 100-70 kPa thickness. 11. MAM. Values in excess of 30 are significant at the 5% level.

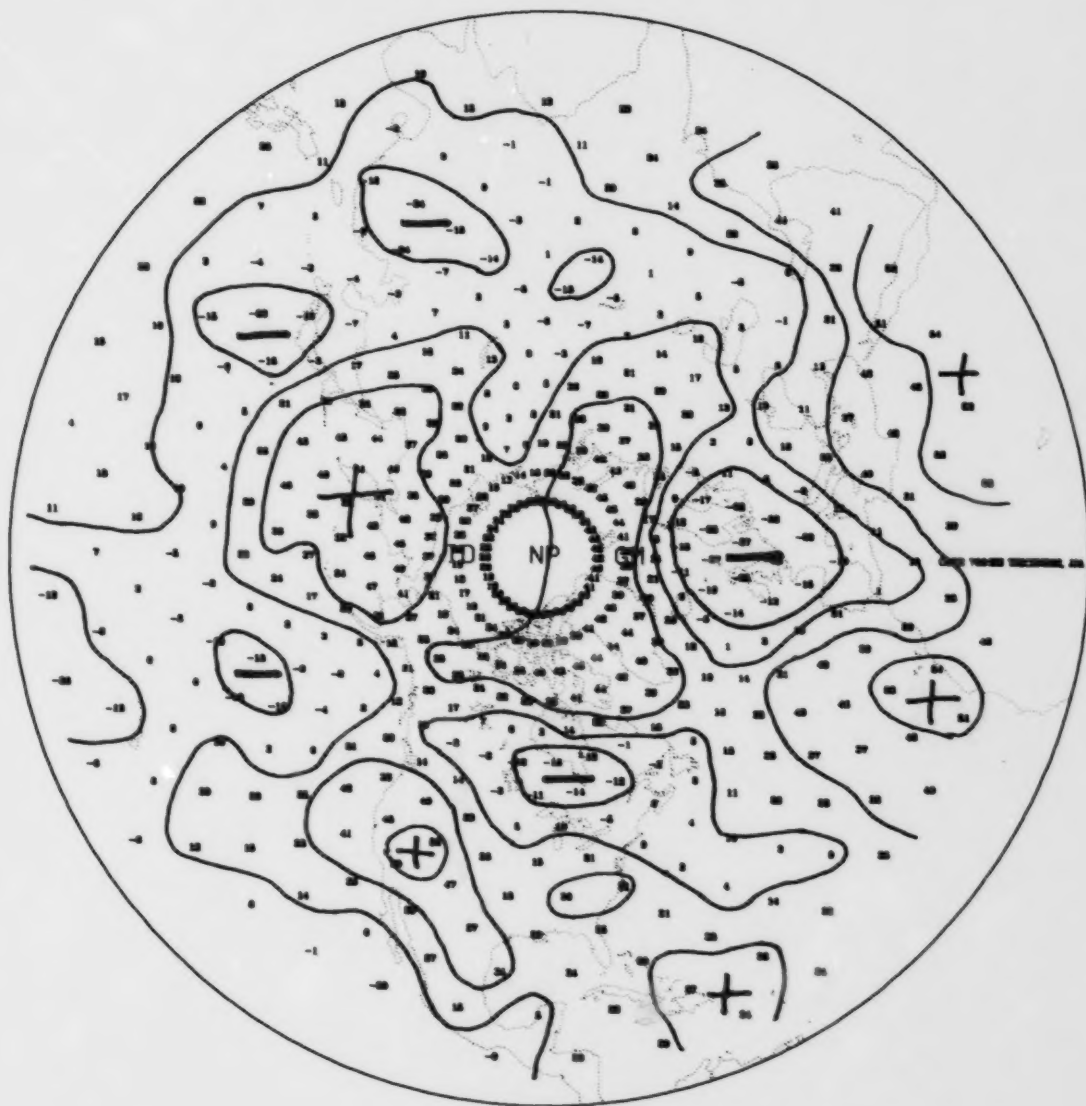


Fig. 18b. Correlation coefficients (x100) of northern hemisphere 70 kPa heights with Arctic 100-70 kPa thickness. iii. JJA. Values in excess of 30 are significant at the 5% level.

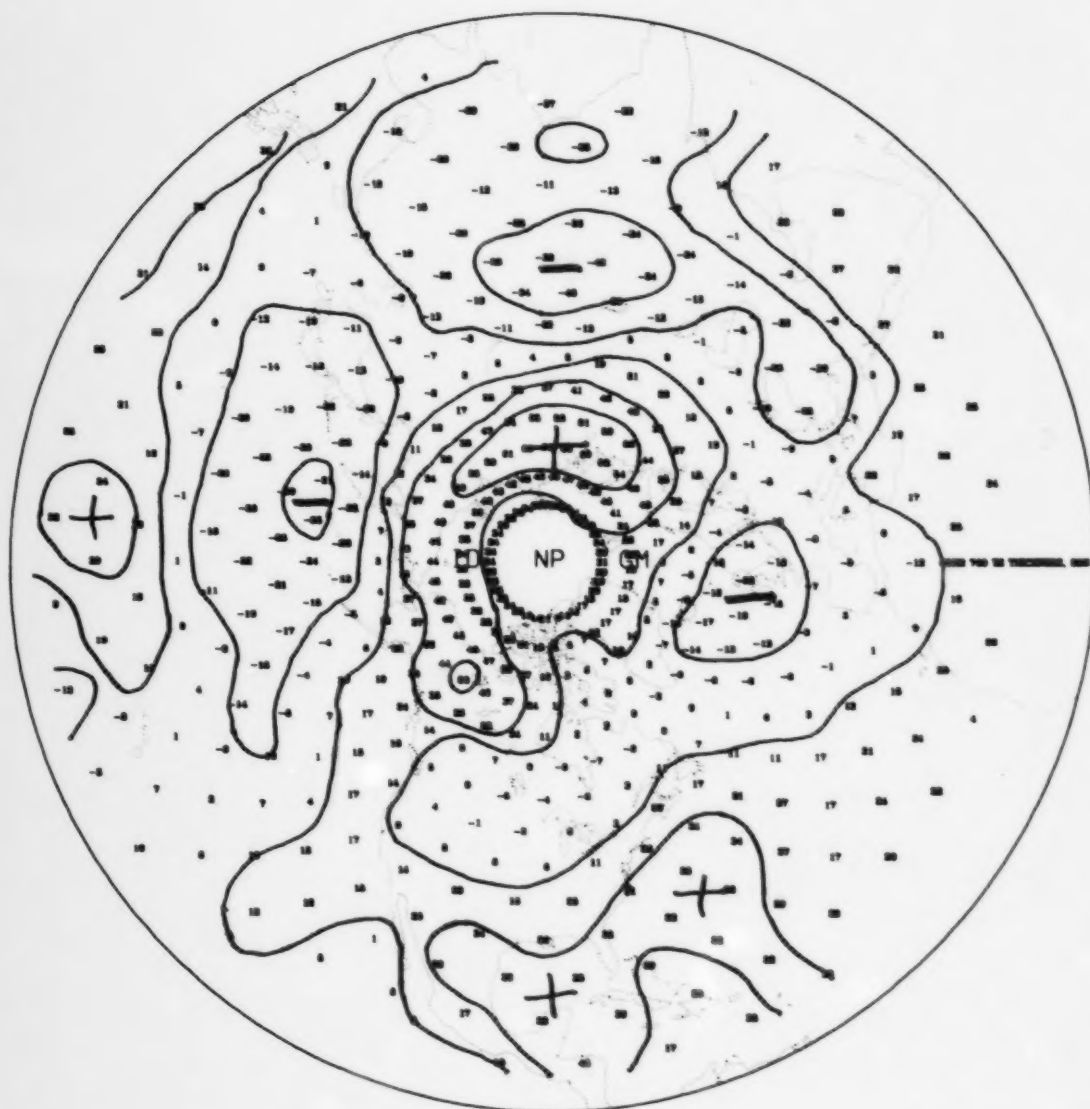


Fig. 18b. Correlation coefficients (x100) of northern hemisphere 70 kPa heights with Arctic 100-70 kPa thickness. iv. SON. Values in excess of 30 are significant at the 5% level.

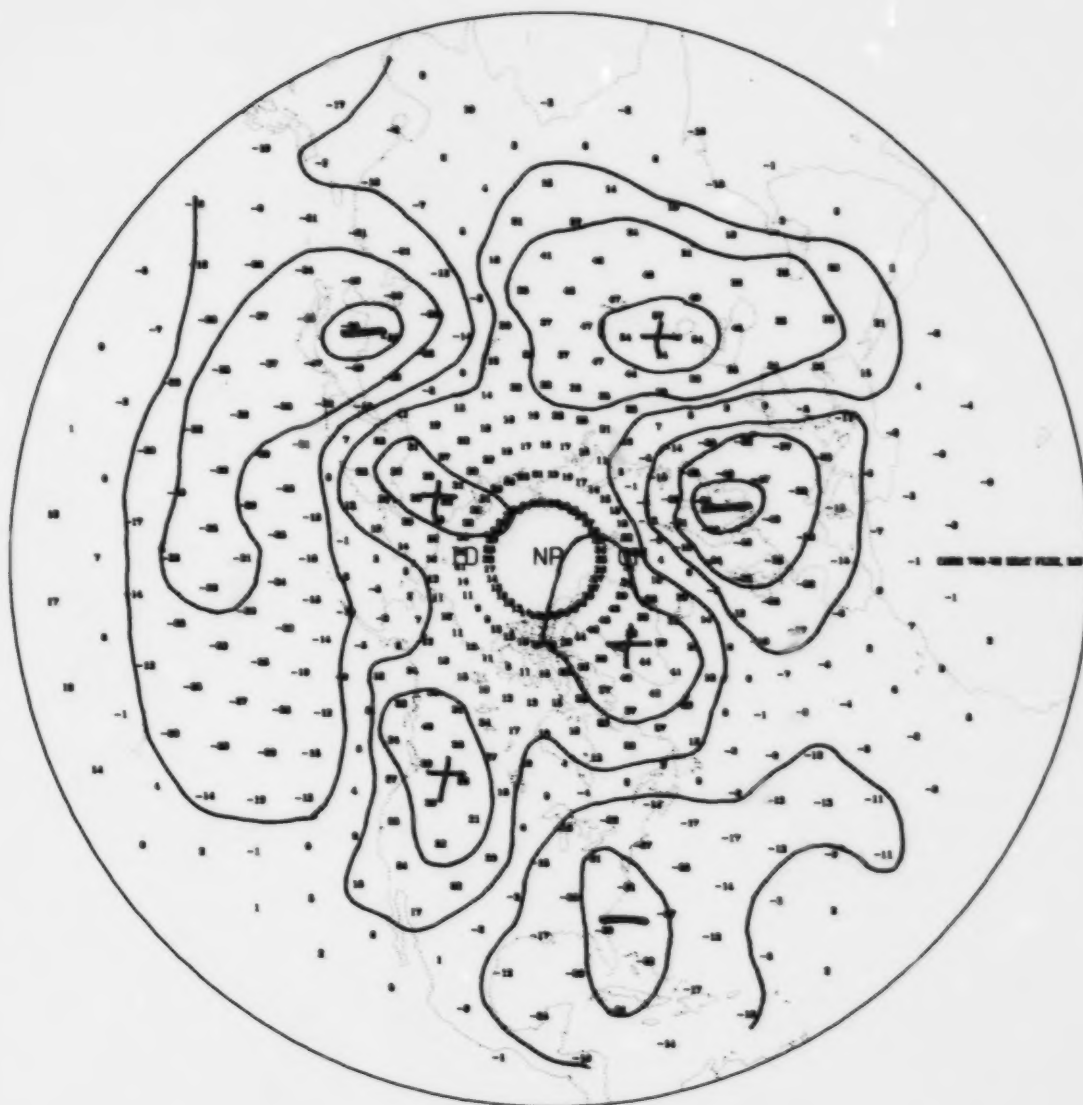


Fig. 18c. Correlation coefficients ($\times 100$) of northern hemisphere 70 kPa heights with Arctic MMC heat flux. 1. DJF. Values in excess of 30 are significant at the 5% level.

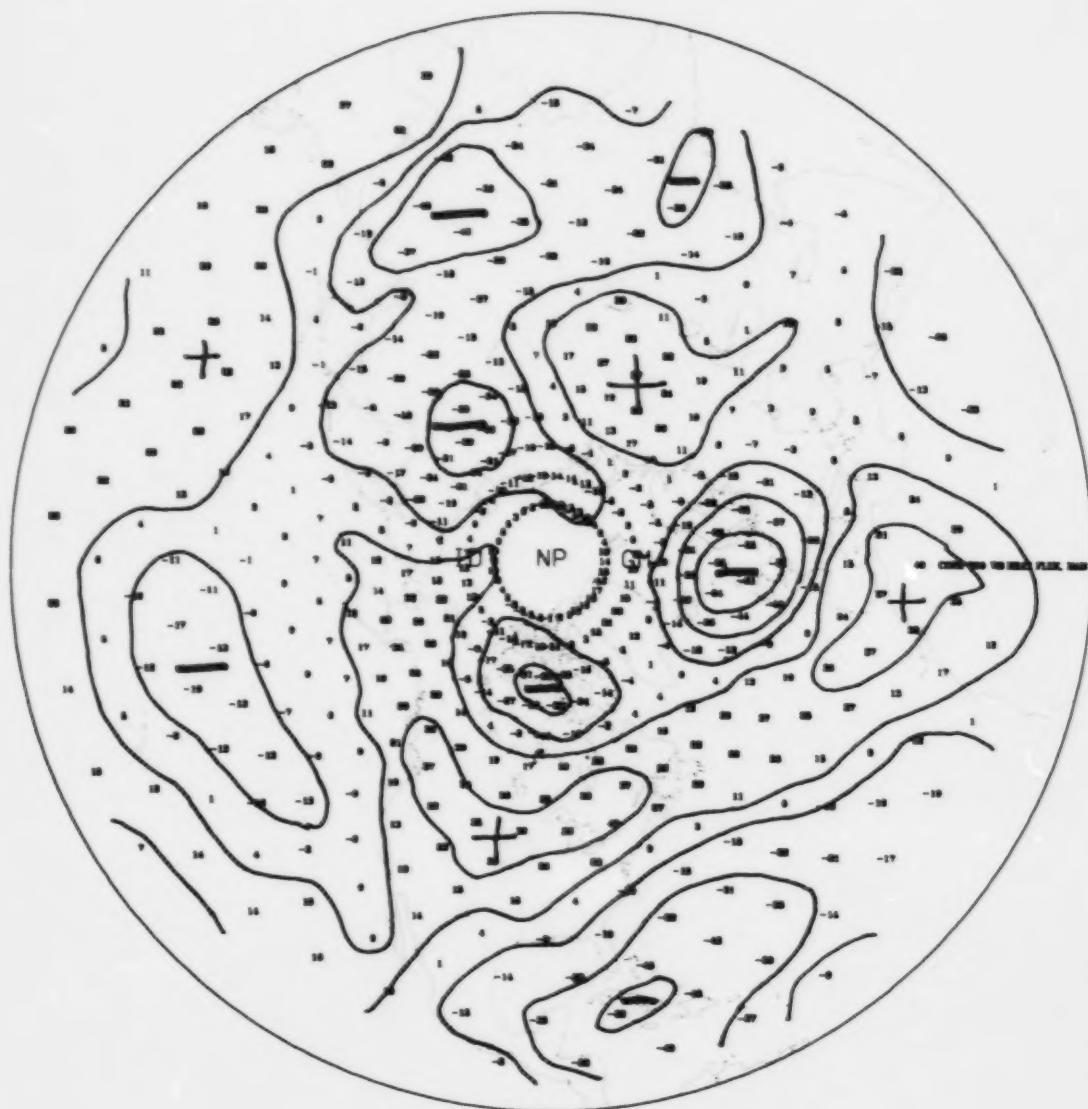


Fig. 18c. Correlation coefficients (x100) of northern hemisphere 70 kPa heights with Arctic MMC heat flux. ii. NAM. Values in excess of 30 are significant at the 5% level.

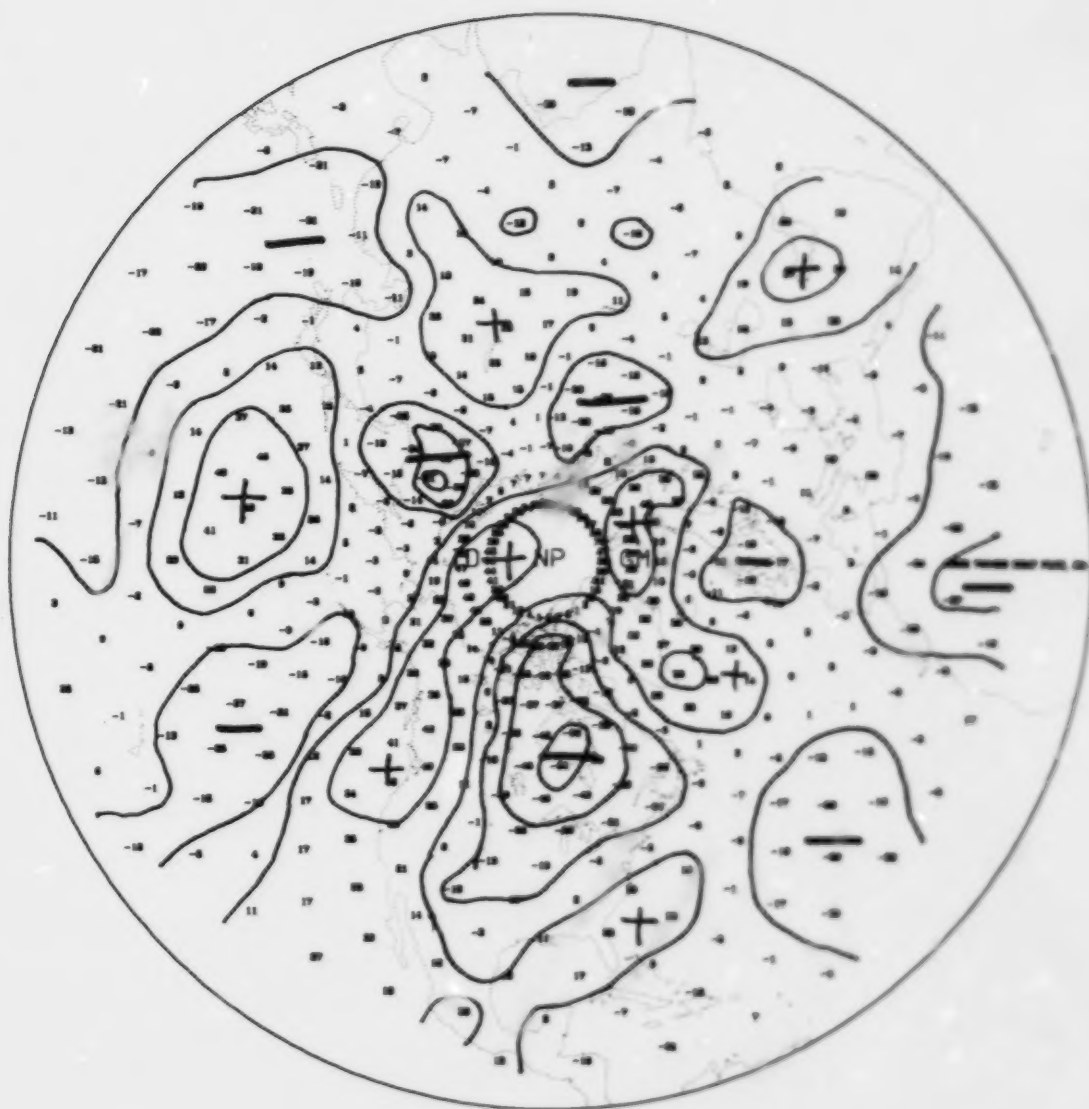


Fig. 18c. Correlation coefficients (x100) of northern hemisphere 70 kPa heights with Arctic MNC heat flux. iii. JJA. Values in excess of 30 are significant at the 5% level.

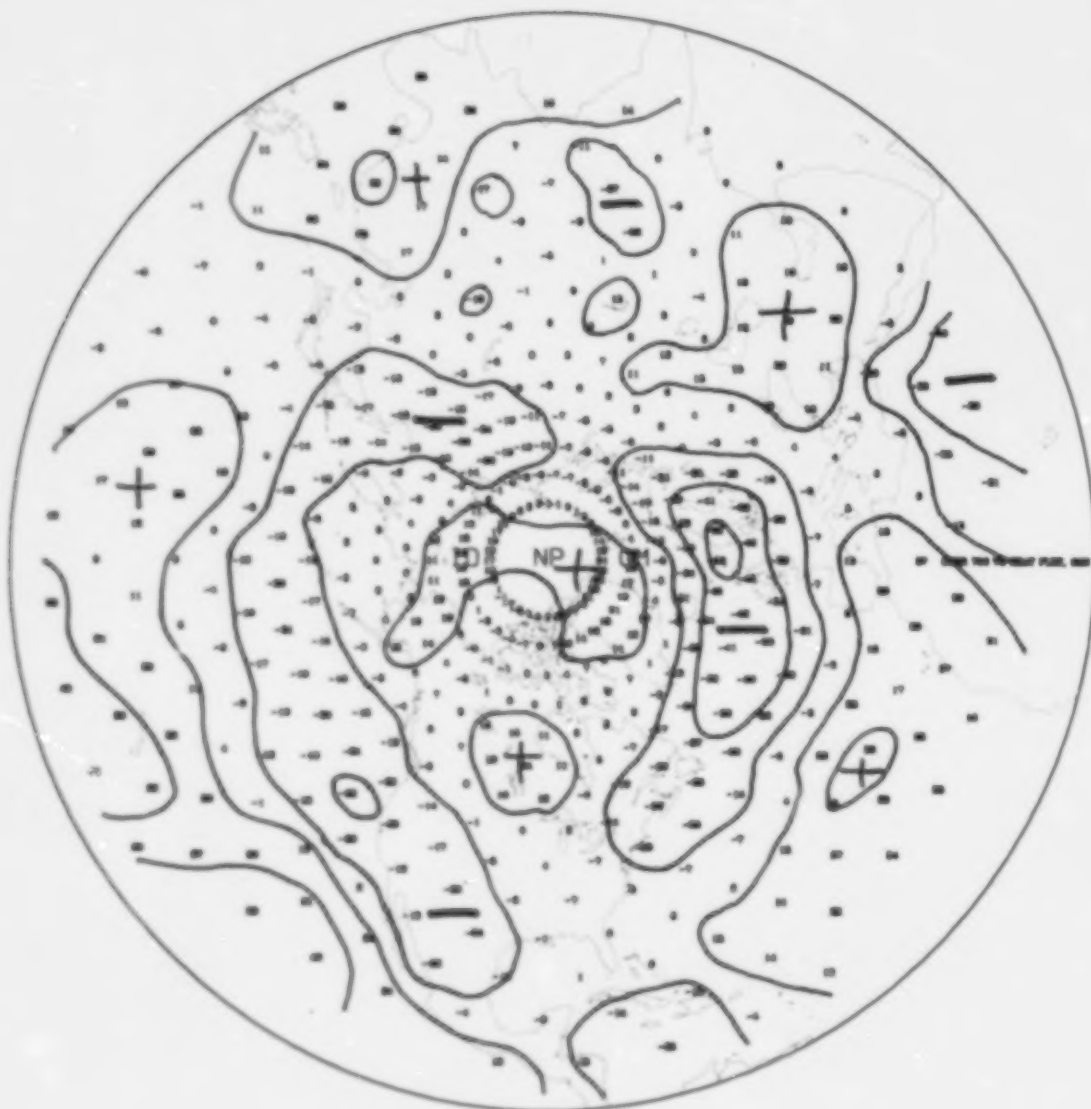


Fig. 18c. Correlation coefficients (x100) of northern hemisphere 70 kPa heights with Arctic MNC heat flux. iv. SON. Values in excess of 30 are significant at the 5% level.

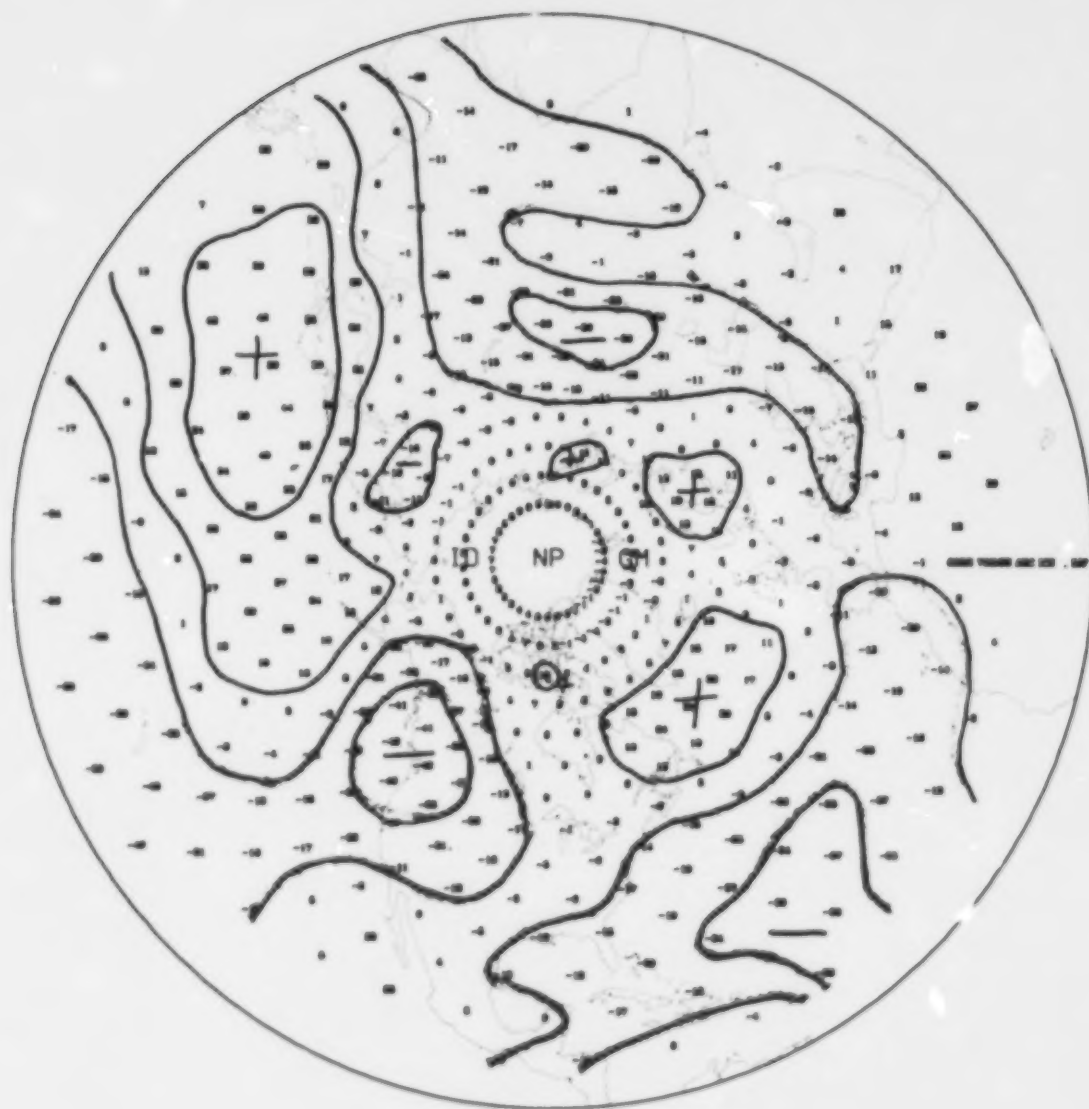


Fig. 18d. Correlation coefficients (x100) of northern hemisphere 70 kPa heights with Arctic sea-ice concentration. 1. DJF. Values in excess of 34 are significant at the 5% level.

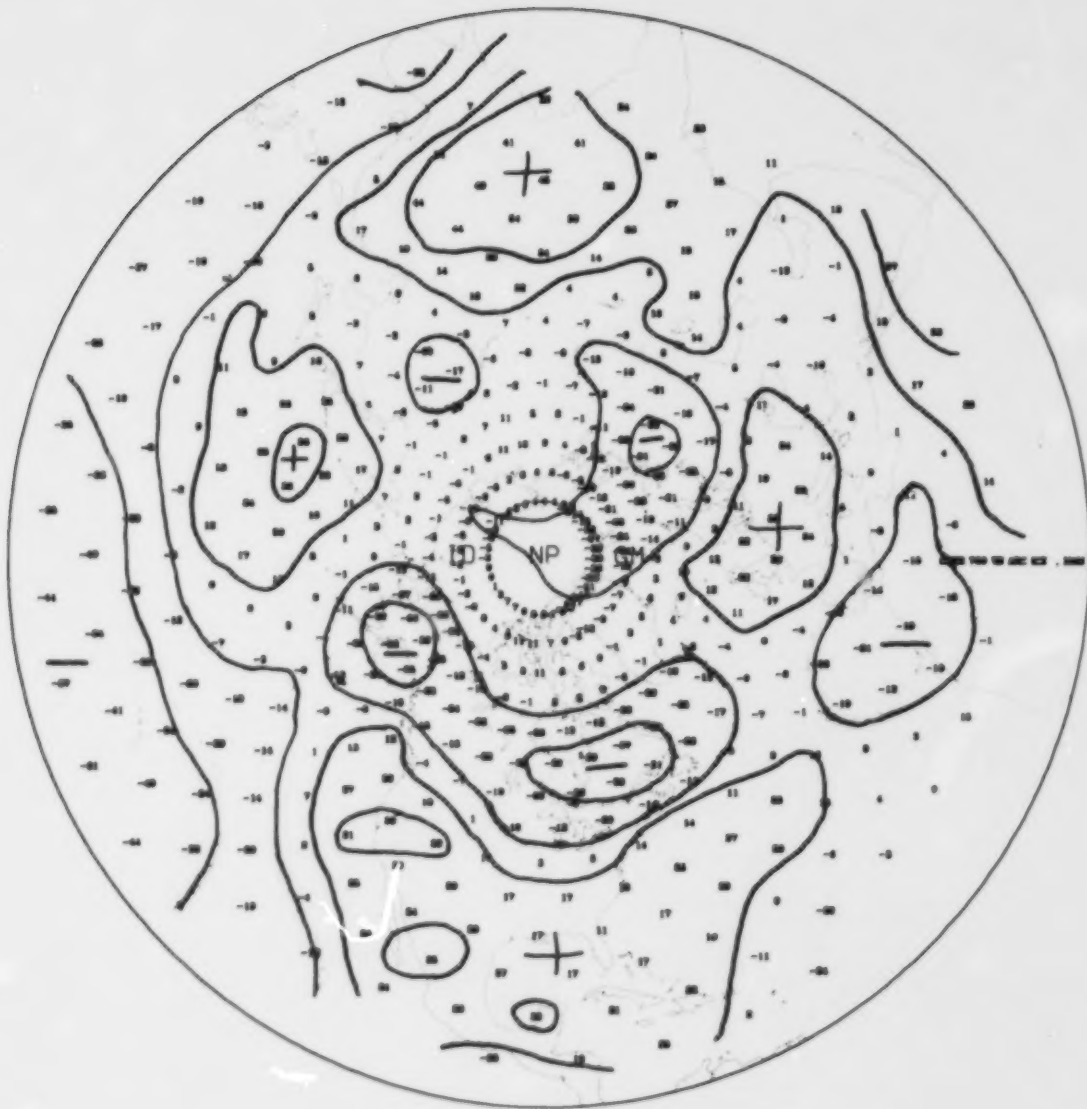


Fig. 18d. Correlation coefficients ($\times 100$) of northern hemisphere 70 kPa heights with Arctic sea-ice concentration. 11. MAM. Values in excess of 34 are significant at the 5% level.

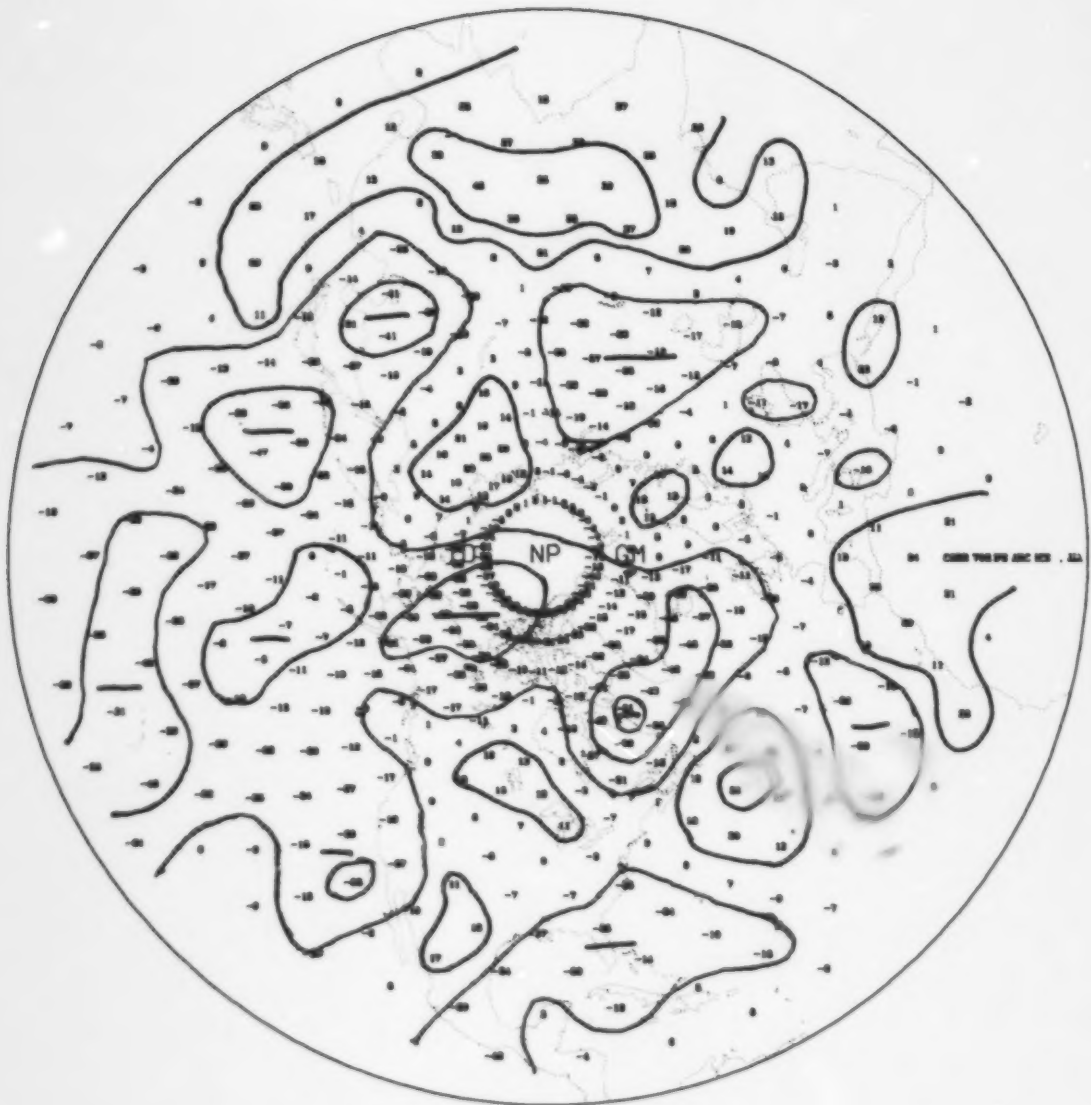


Fig. 18d. Correlation coefficients ($\times 100$) of northern hemisphere 70 kPa heights with Arctic sea-ice concentration. iii. JJA. Values in excess of 34 are significant at the 5% level.

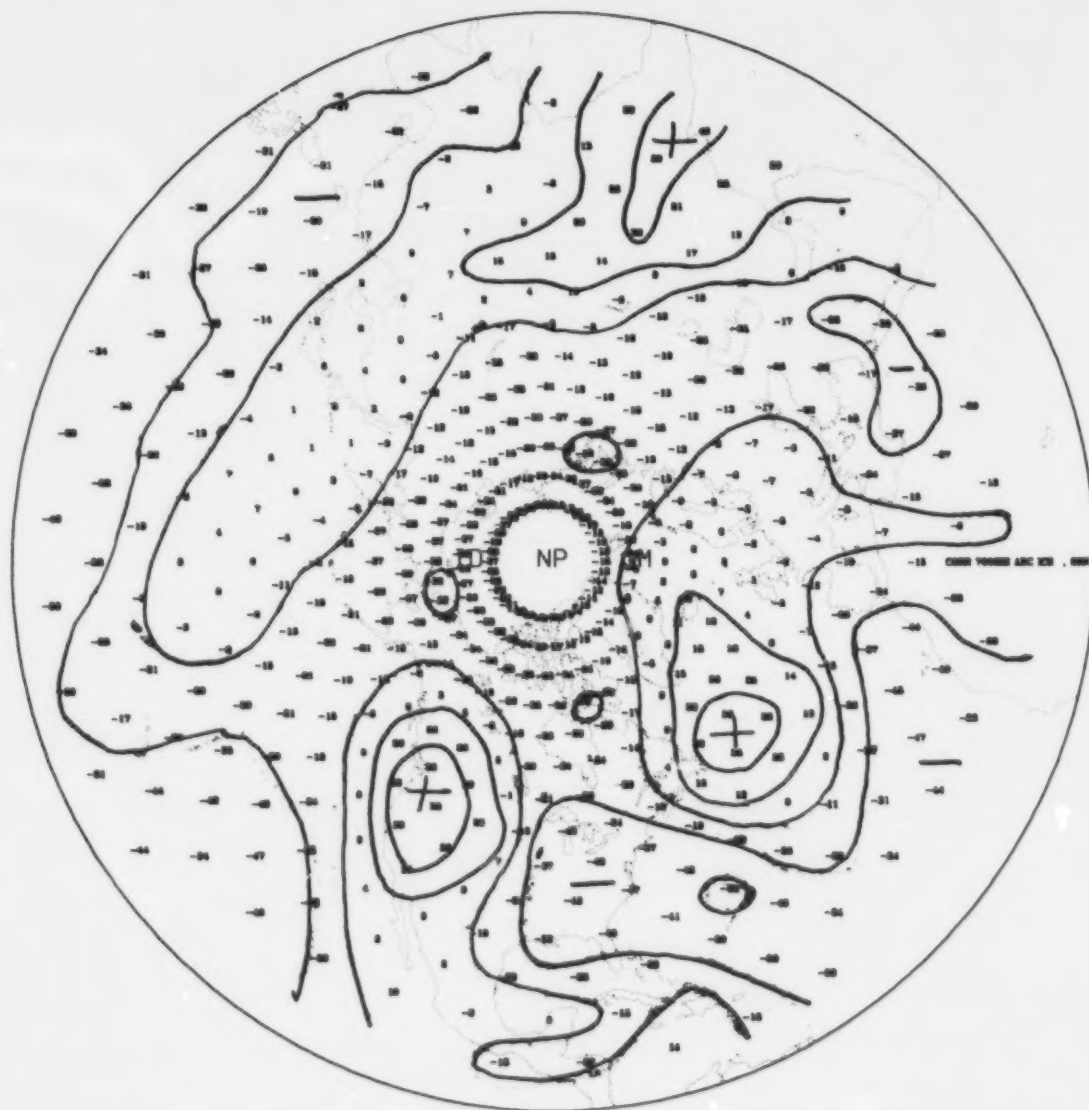


Fig. 18d. Correlation coefficients (x100) of northern hemisphere 70 kPa heights with Arctic sea-ice concentration. iv. SON. Values in excess of 34 are significant at the 5% level.

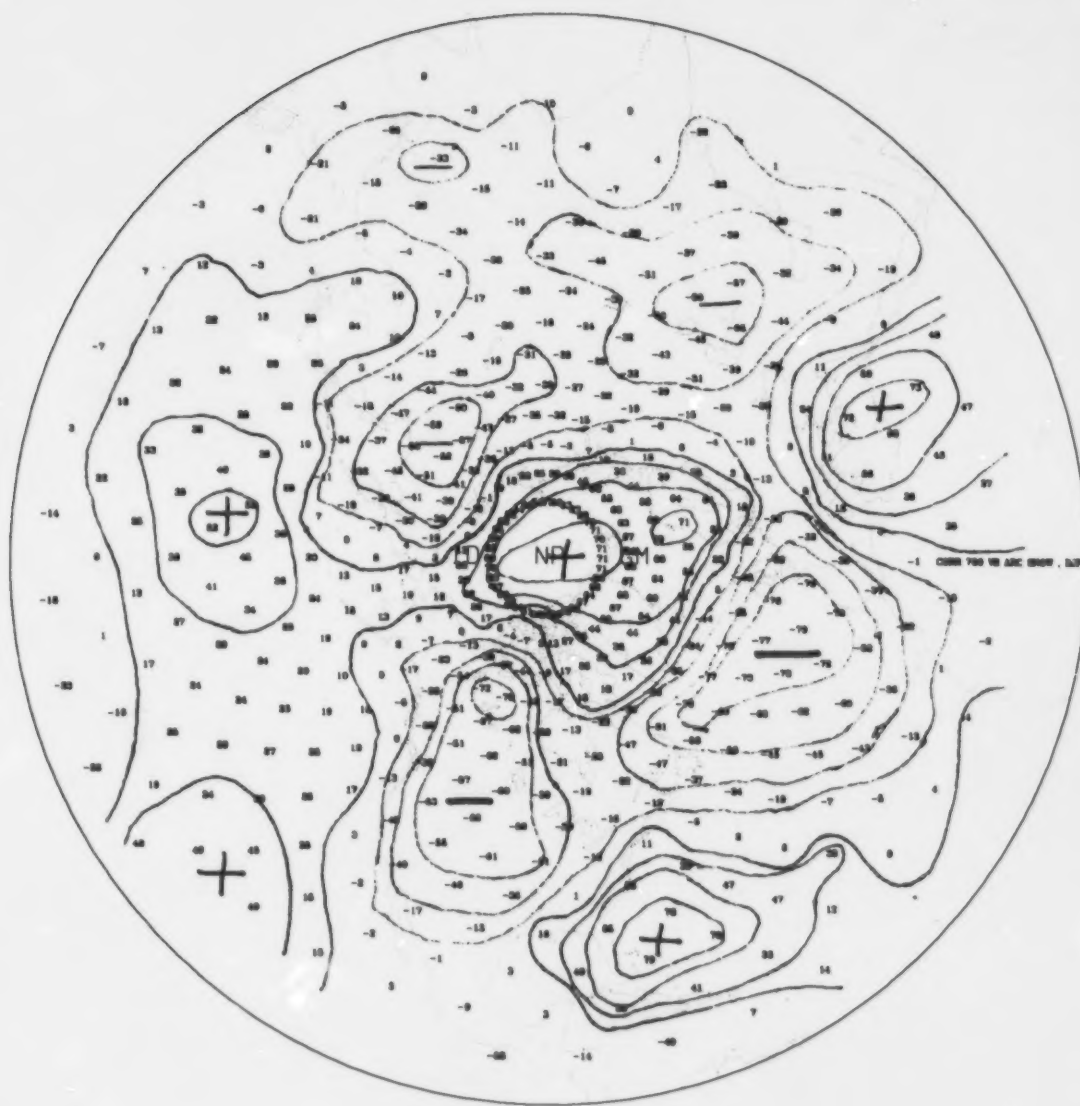


Fig. 18e. Correlation coefficients (x100) of northern hemisphere 70 kPa heights with Arctic snow cover. 1. DJF. Values in excess of 64 are significant at the 5% level.

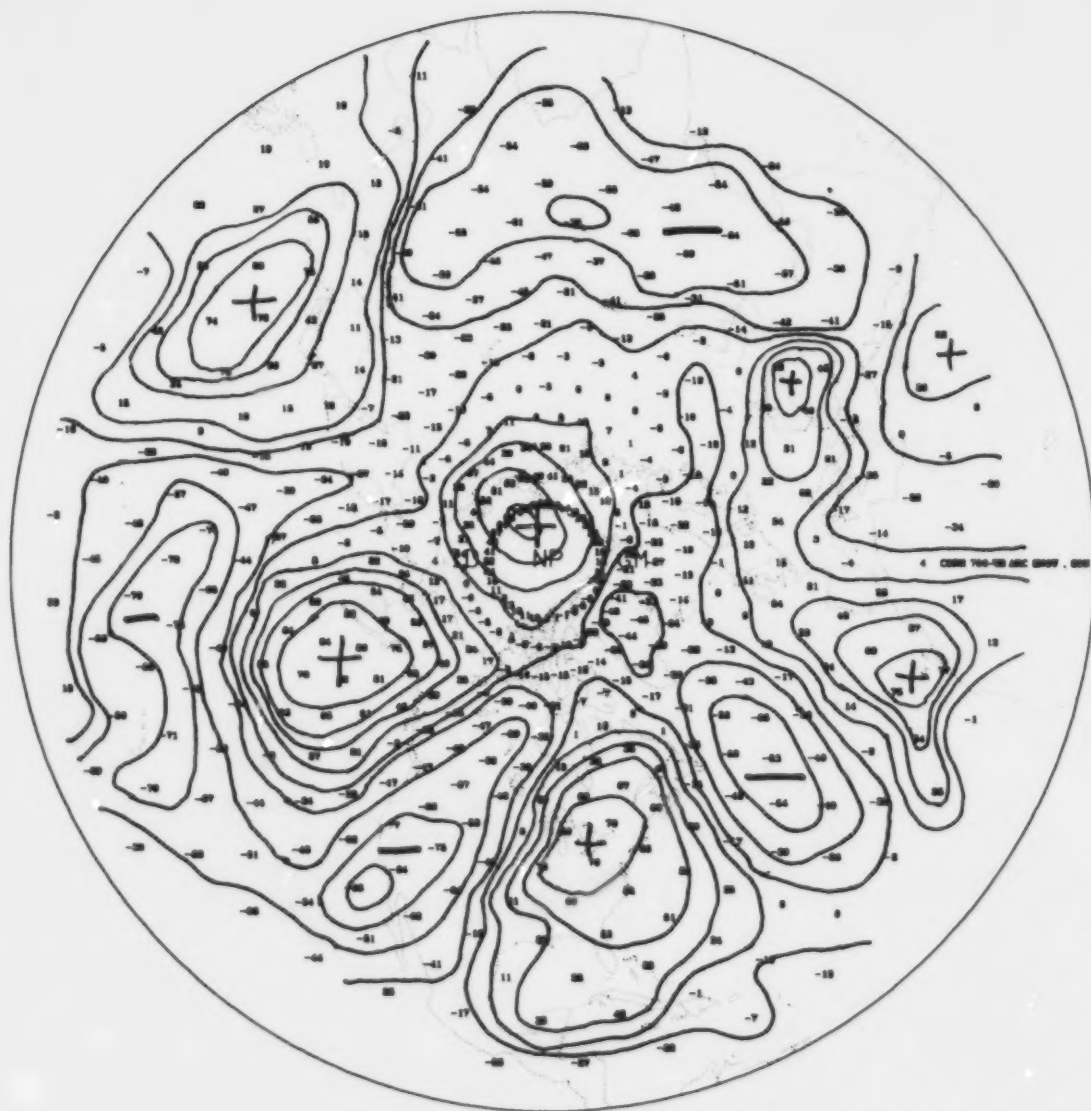


Fig. 18e. Correlation coefficients (x100) of northern hemisphere 70 kPa heights with Arctic snow cover. 11. MAM. Values in excess of 64 are significant at the 5% level.

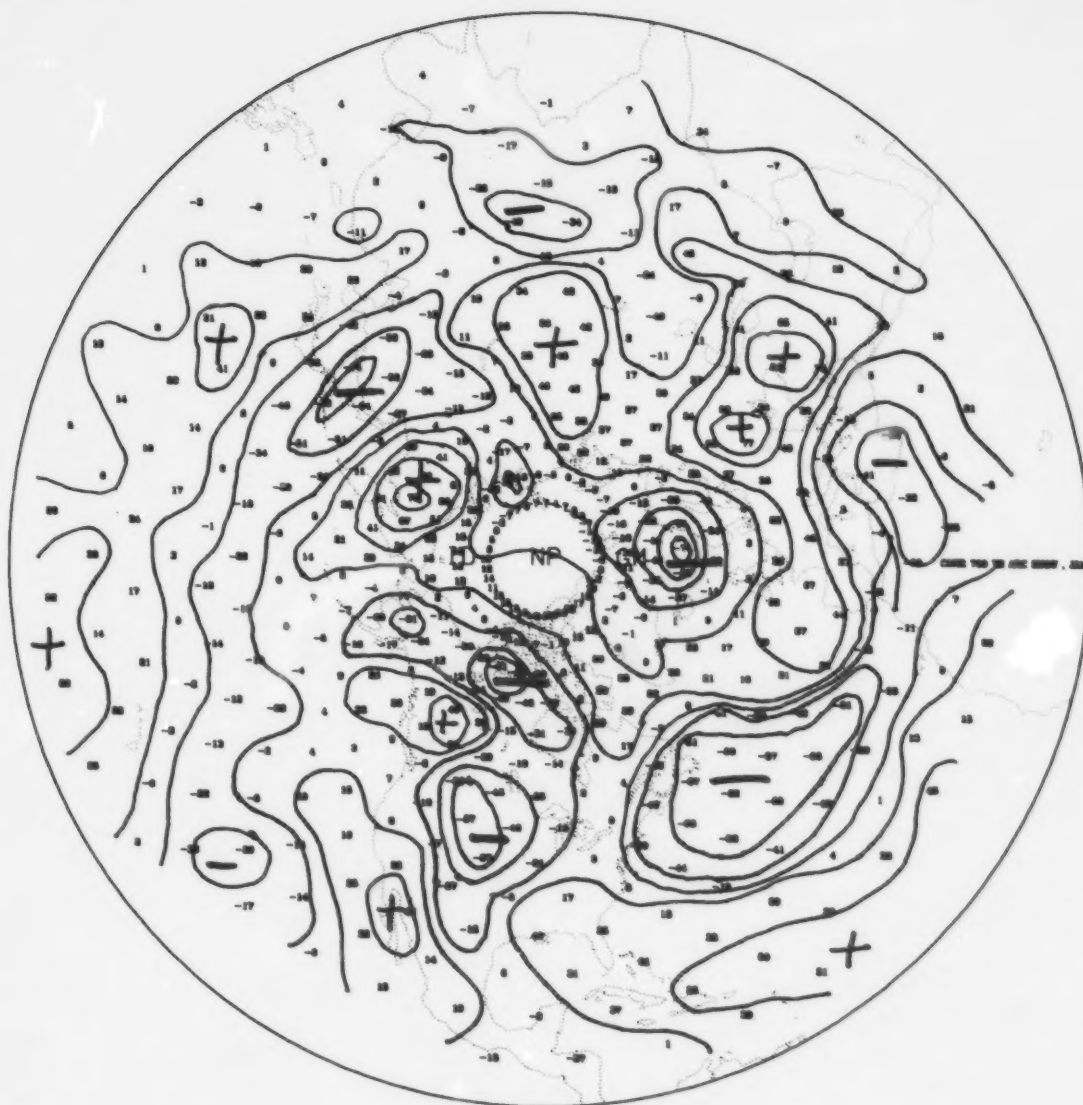


Fig. 18e. Correlation coefficients ($\times 100$) of northern hemisphere 70 kPa heights with Arctic snow cover. iii. JJA. Values in excess of 64 are significant at the 5% level.

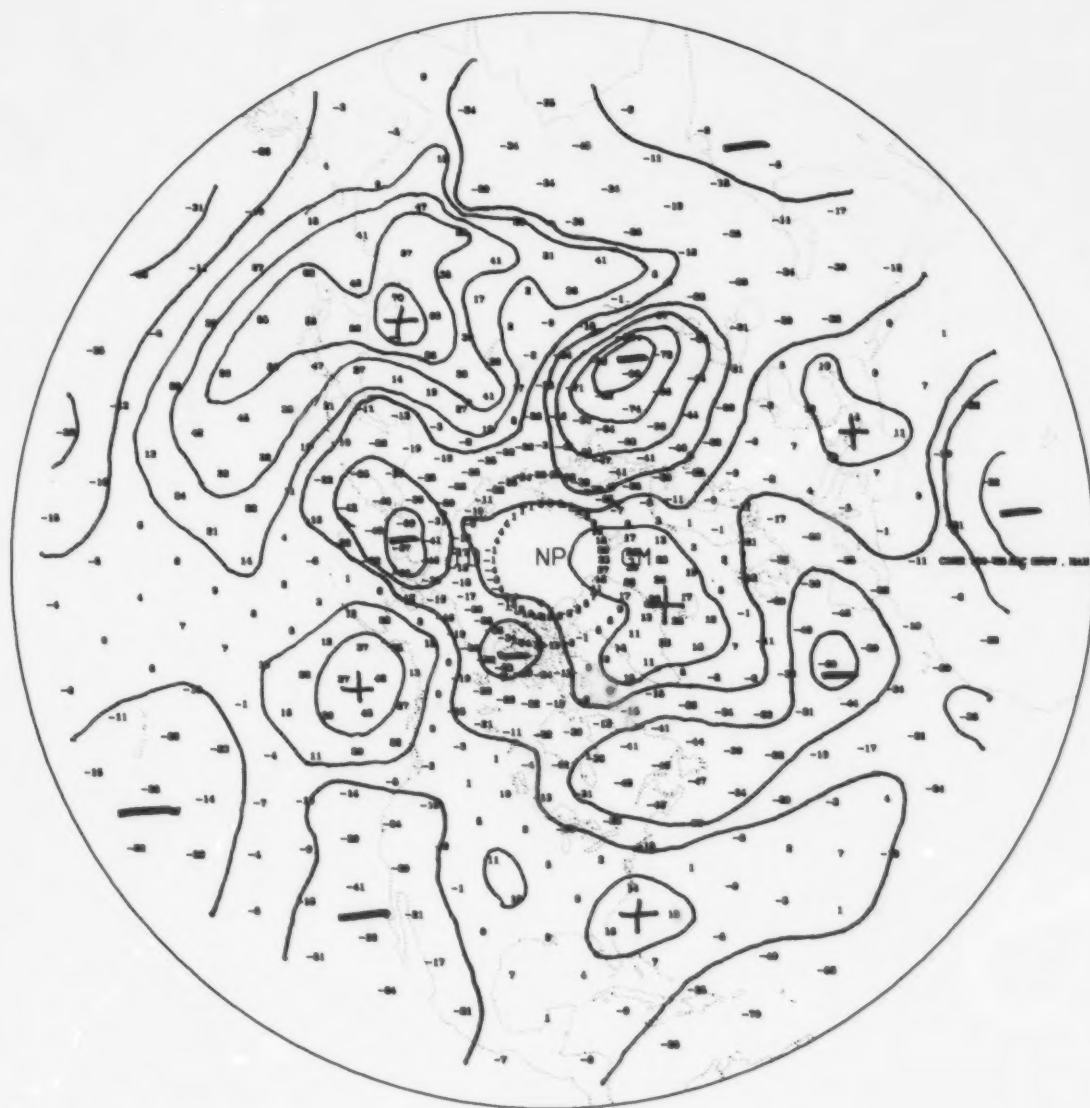


Fig. 18e. Correlation coefficients (x100) of northern hemisphere 70 kPa heights with Arctic snow cover. iv. SON. Values in excess of 64 are significant at the 5% level.



Fig. 19. Average Arctic ice concentration anomalies for
composited dry-wet months on the Canadian Prairies.
a. DJF.

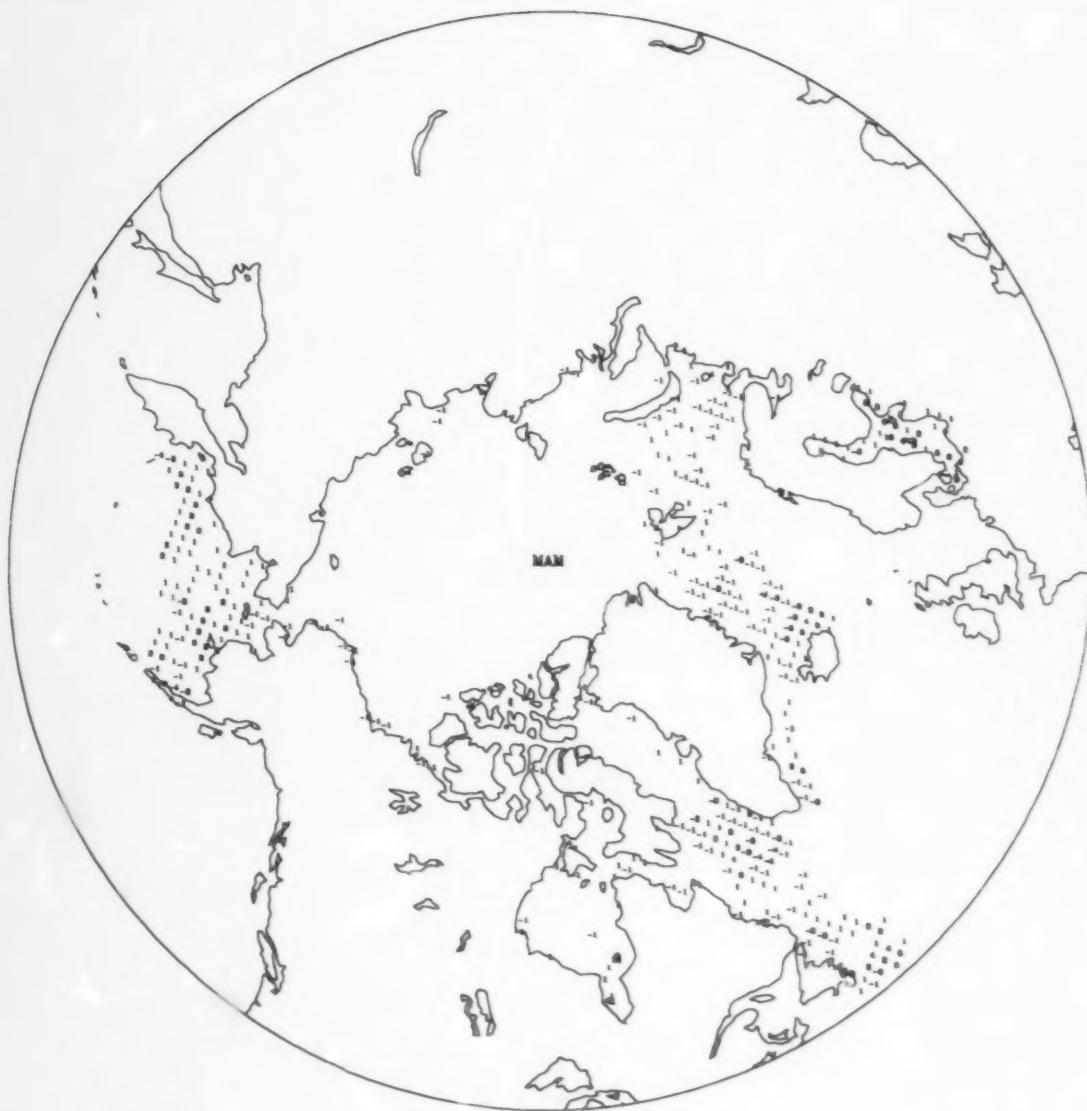


Fig. 19. Average Arctic ice concentration anomalies for composited dry-wet months on the Canadian Prairies.
b. MAM.



Fig. 19. Average Arctic ice concentration anomalies for composited dry-wet months on the Canadian Prairies. c. JJA.

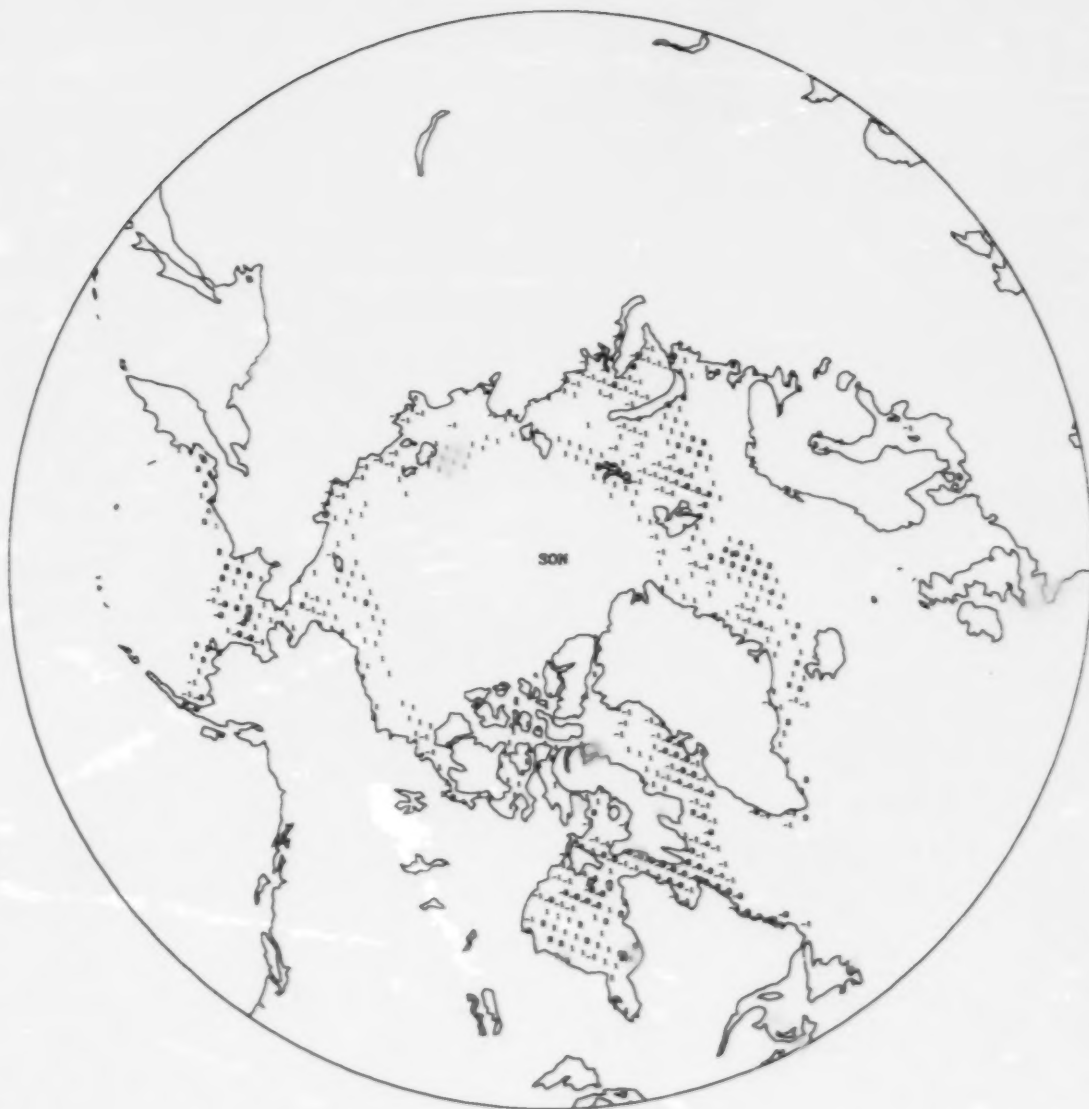


Fig. 19. Average Arctic ice concentration anomalies for composited dry-wet months on the Canadian Prairies. d. SON.

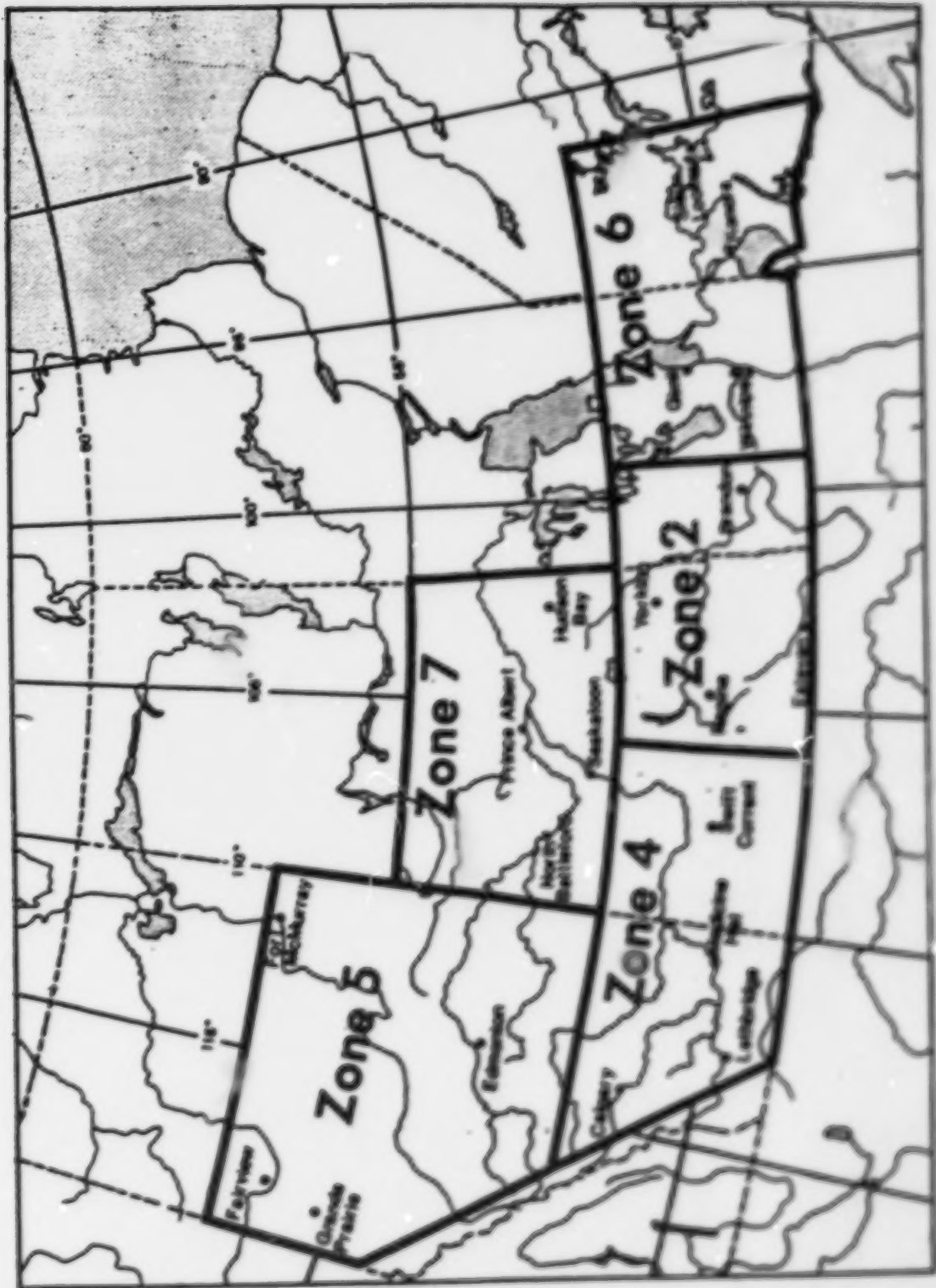


Fig. 20. Zones of coherent precipitation patterns on the Canadian Prairies (Knox and Lawford, 1990).

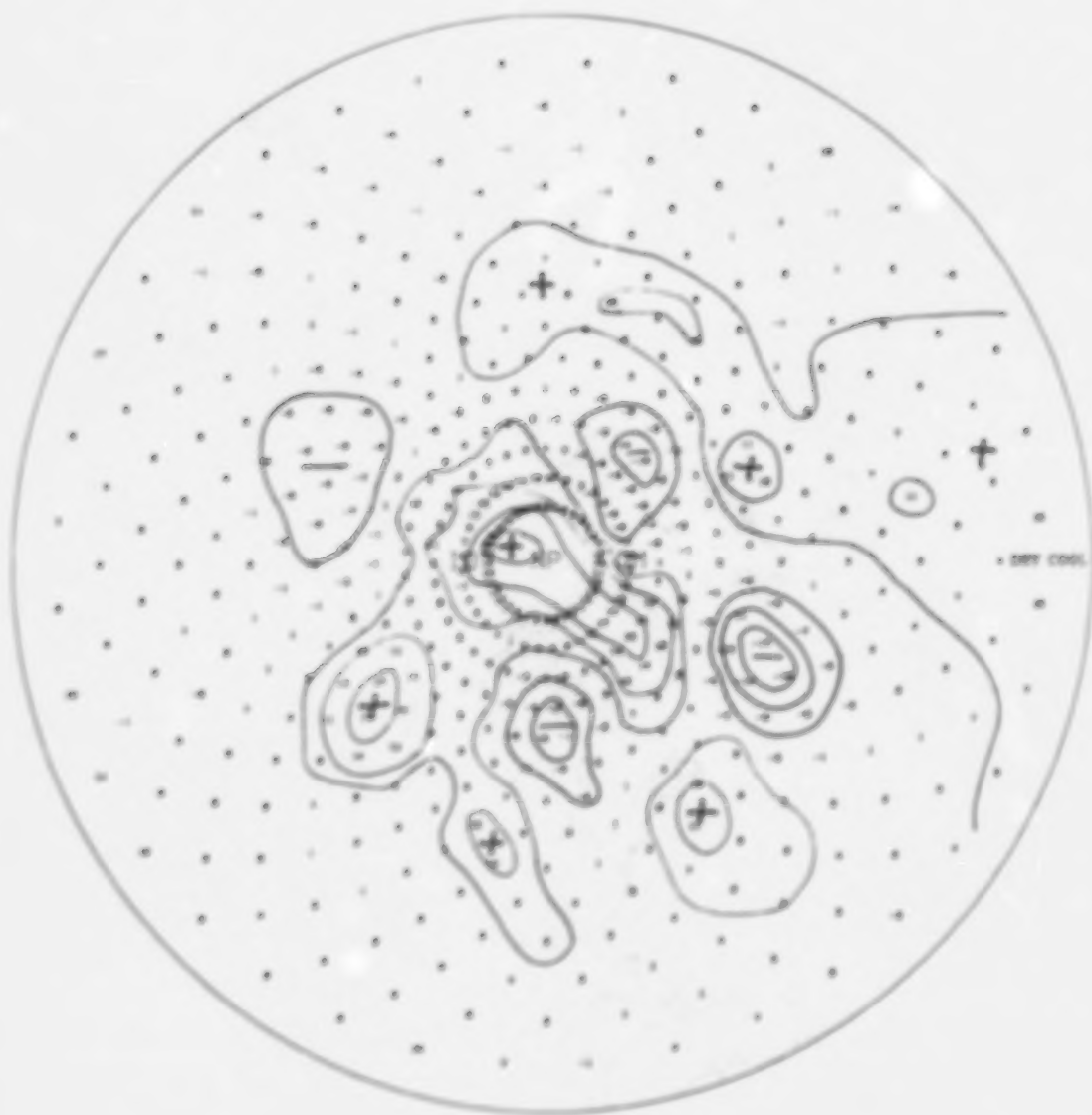


Fig. 21a. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 2, dry cool conditions.



Fig. 21b. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 2, wet cool conditions.

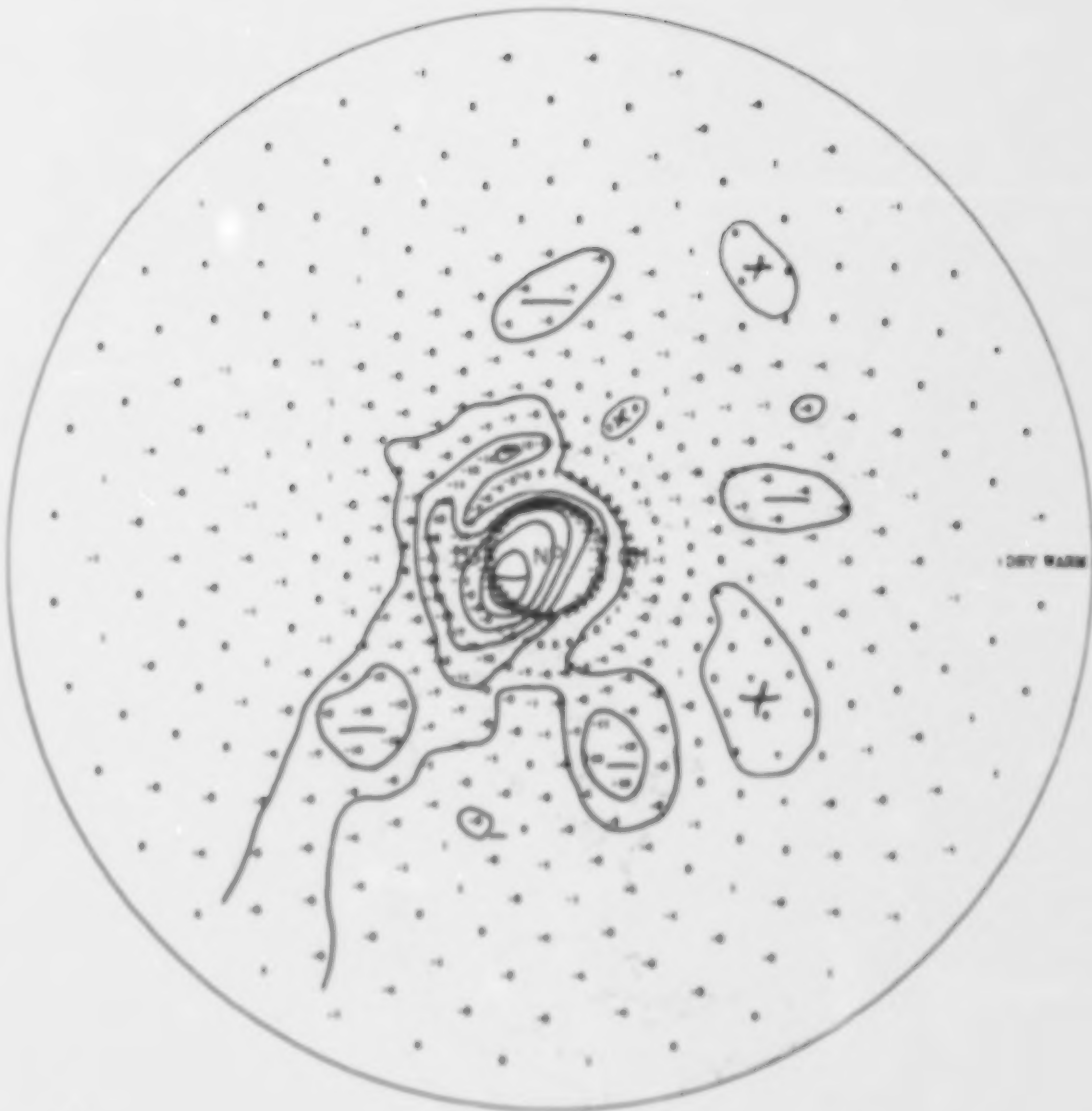


Fig. 21c. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 2, dry warm conditions.

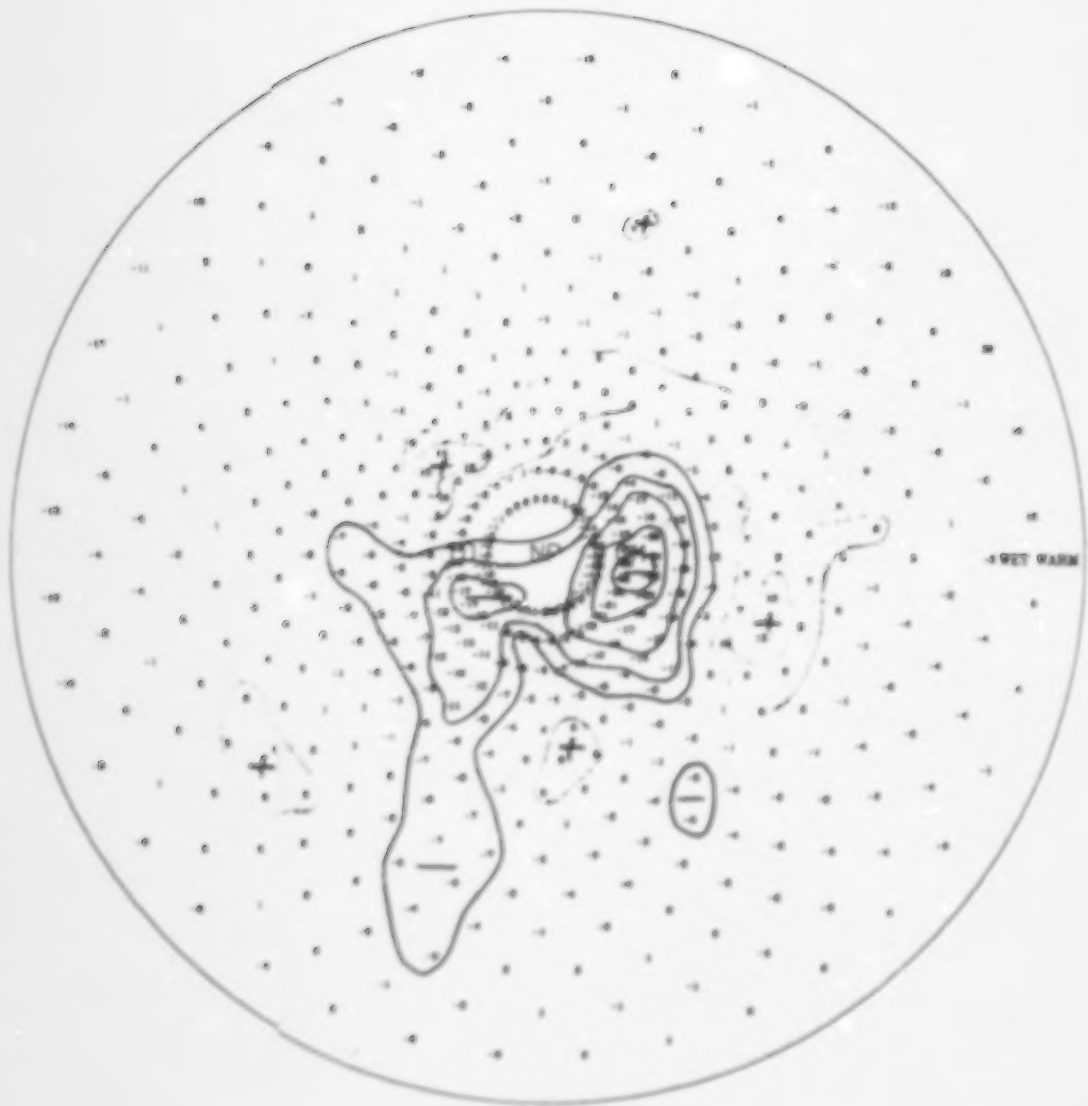


Fig. 21d. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 2, wet warm conditions.

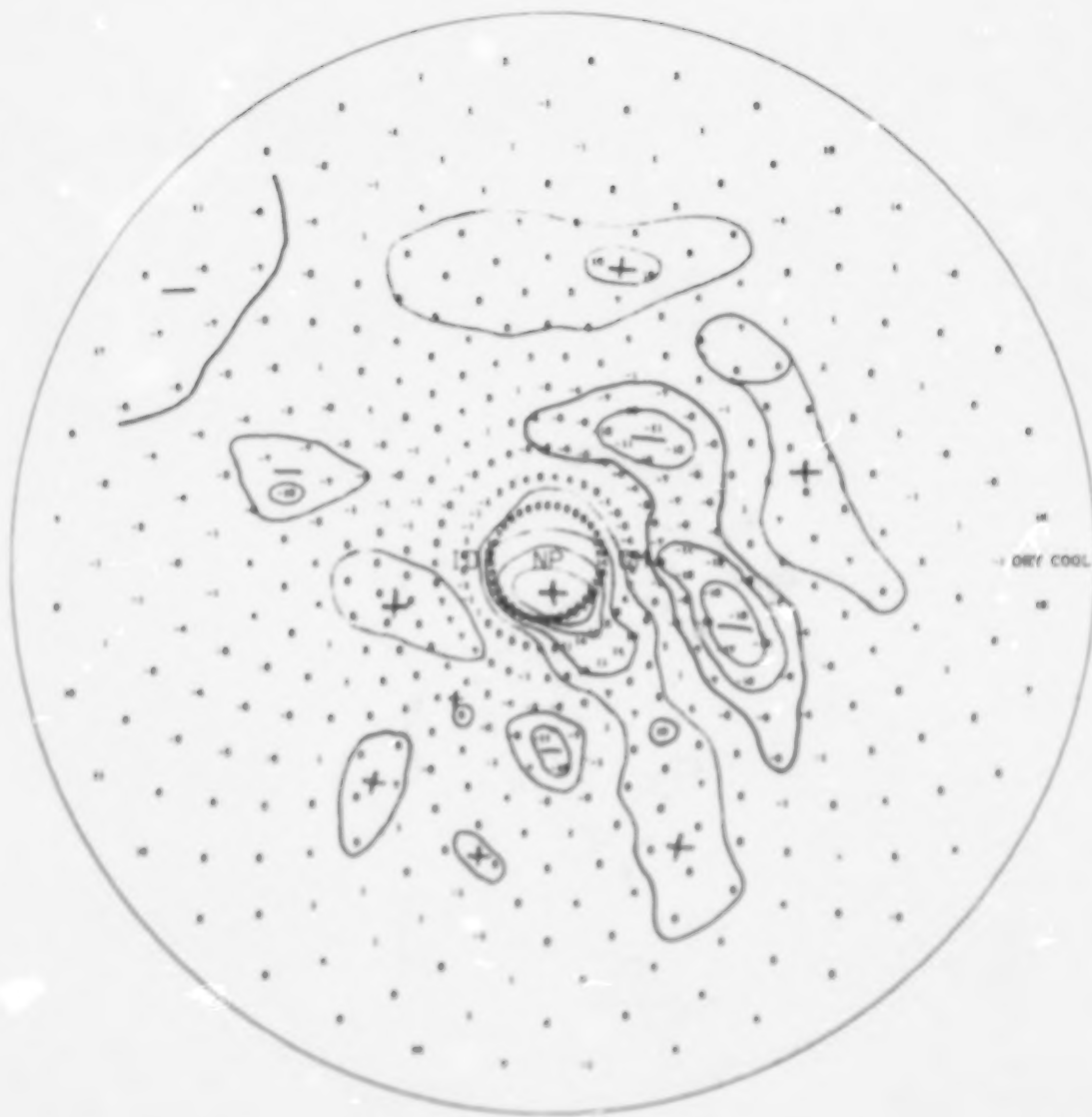


Fig. 21e. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 4, dry cool conditions.



Fig. 21f. Compoited northern hemisphere sea-level pressure anomalies for Prairie zone 4, wet cool conditions.

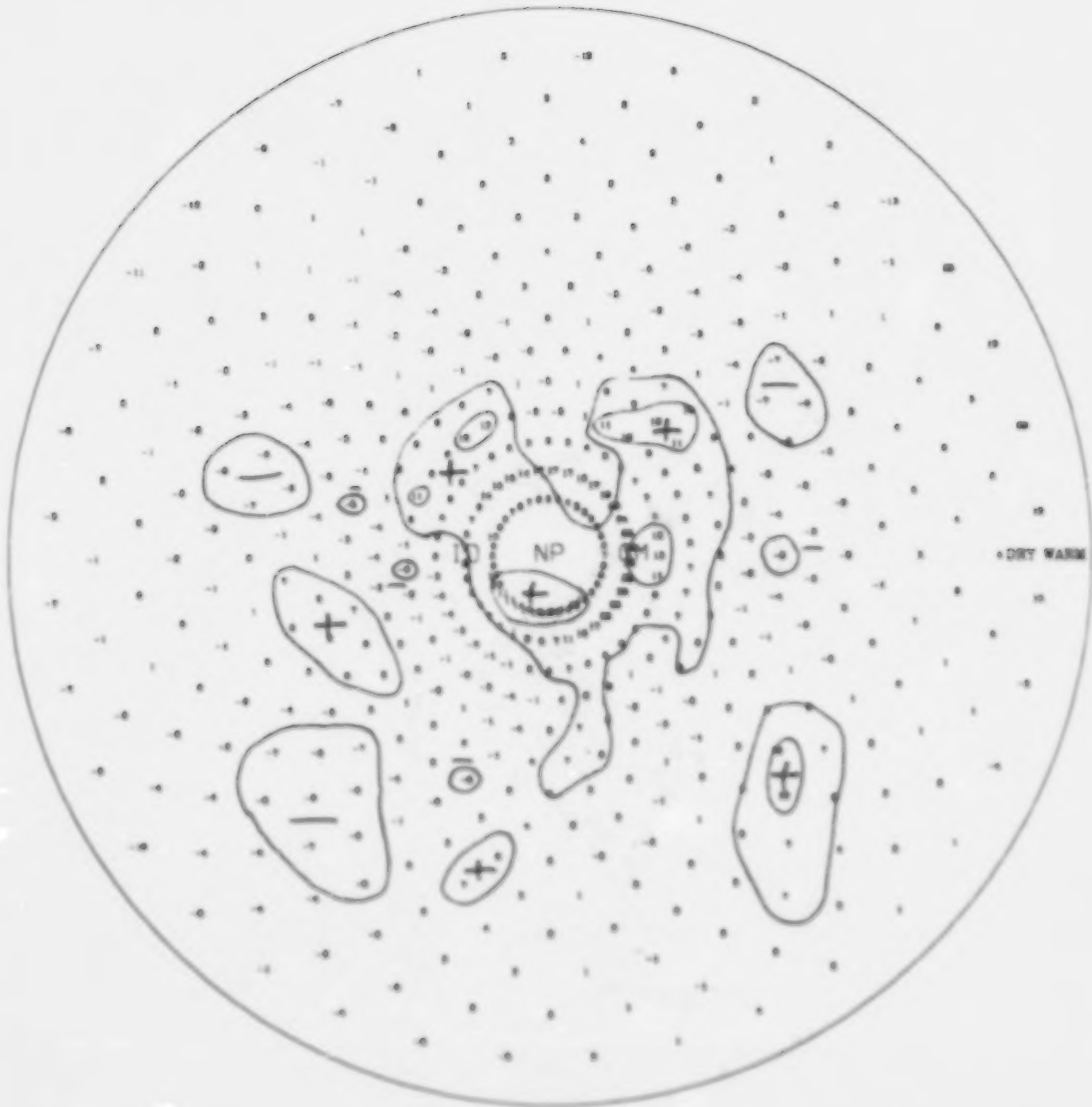


Fig. 21g. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 4, dry warm conditions.

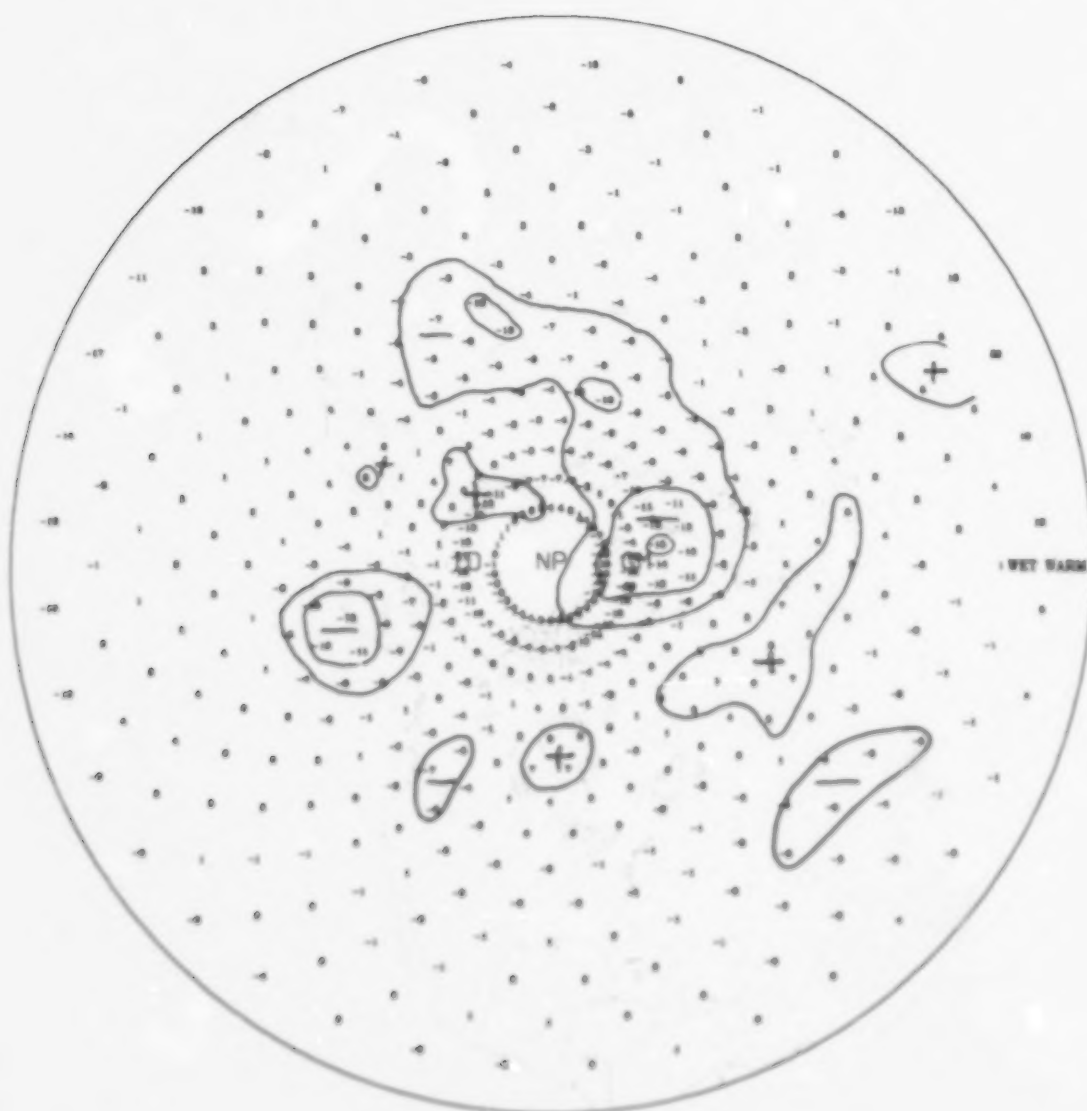


Fig. 21h. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 4, wet warm conditions.



Fig. 211. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 3, dry cool conditions.

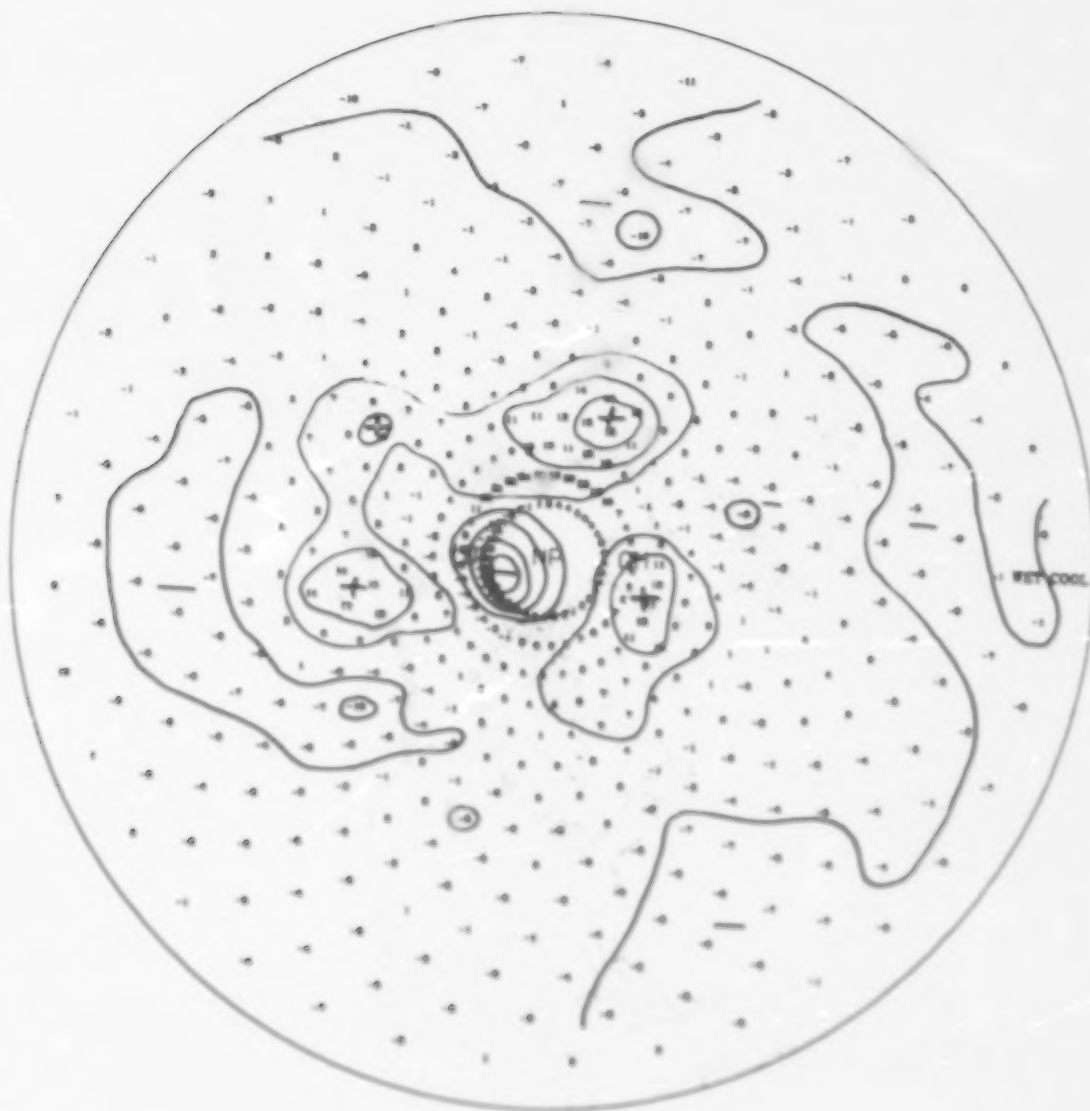


Fig. 21j. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 3, wet cool conditions.

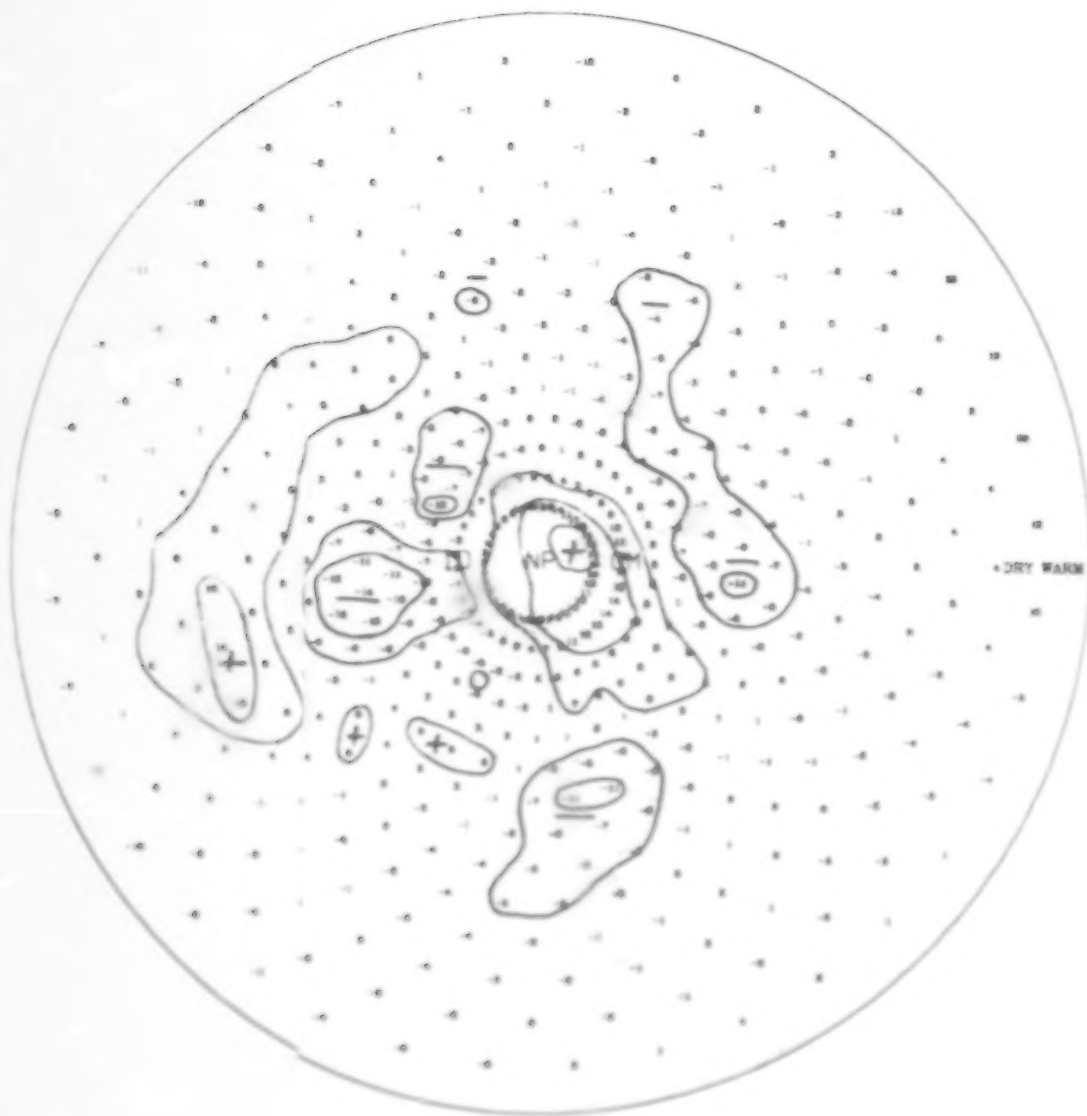


Fig. 31k. Compositd northern hemisphere sea-level pressure anomalies for Prairie zone 3, dry warm conditions.



Fig. 211. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 3, wet warm conditions.

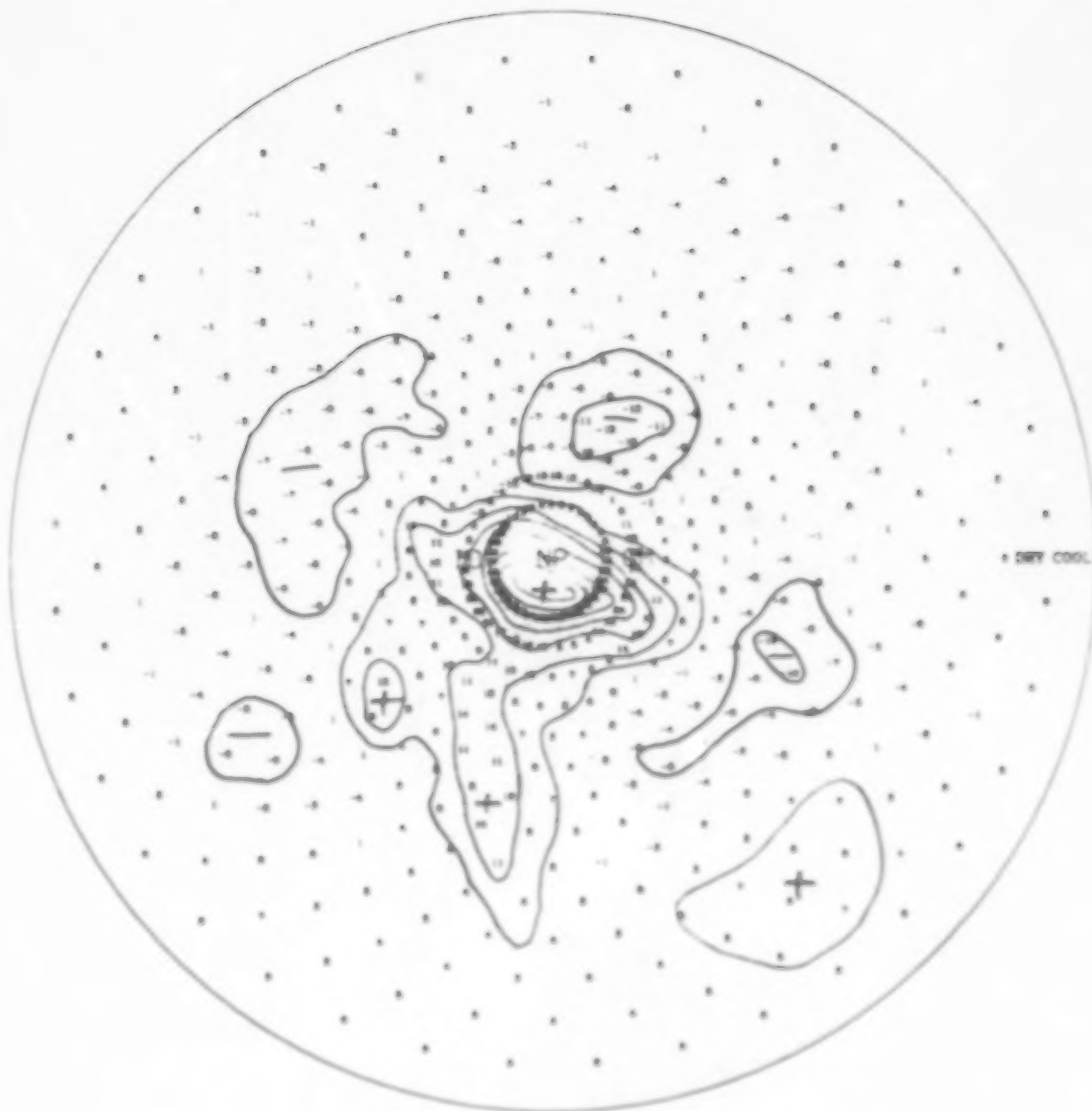


Fig. 21a. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 6, dry cool conditions.

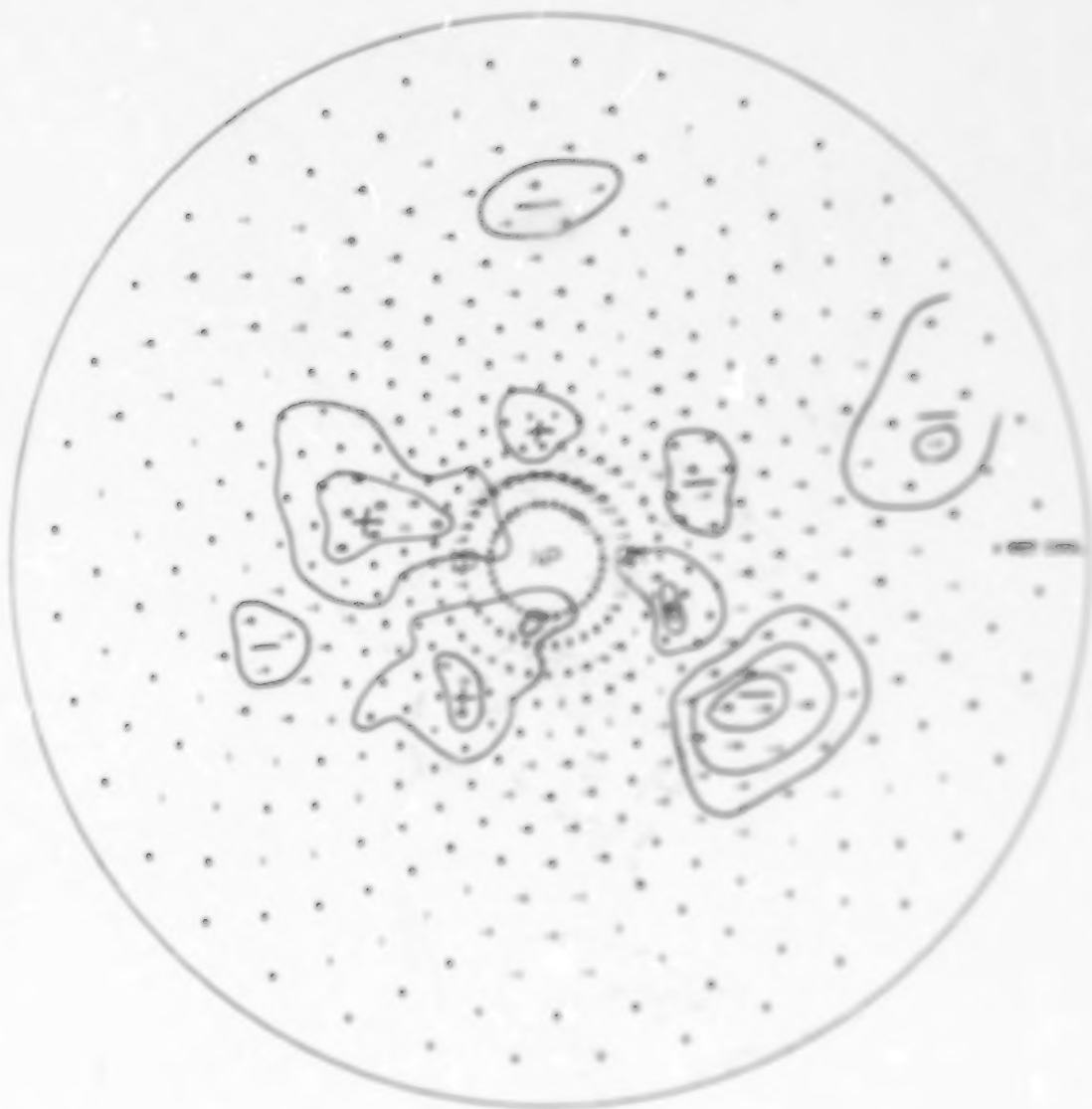


Fig. 21a. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 6, wet cool conditions.

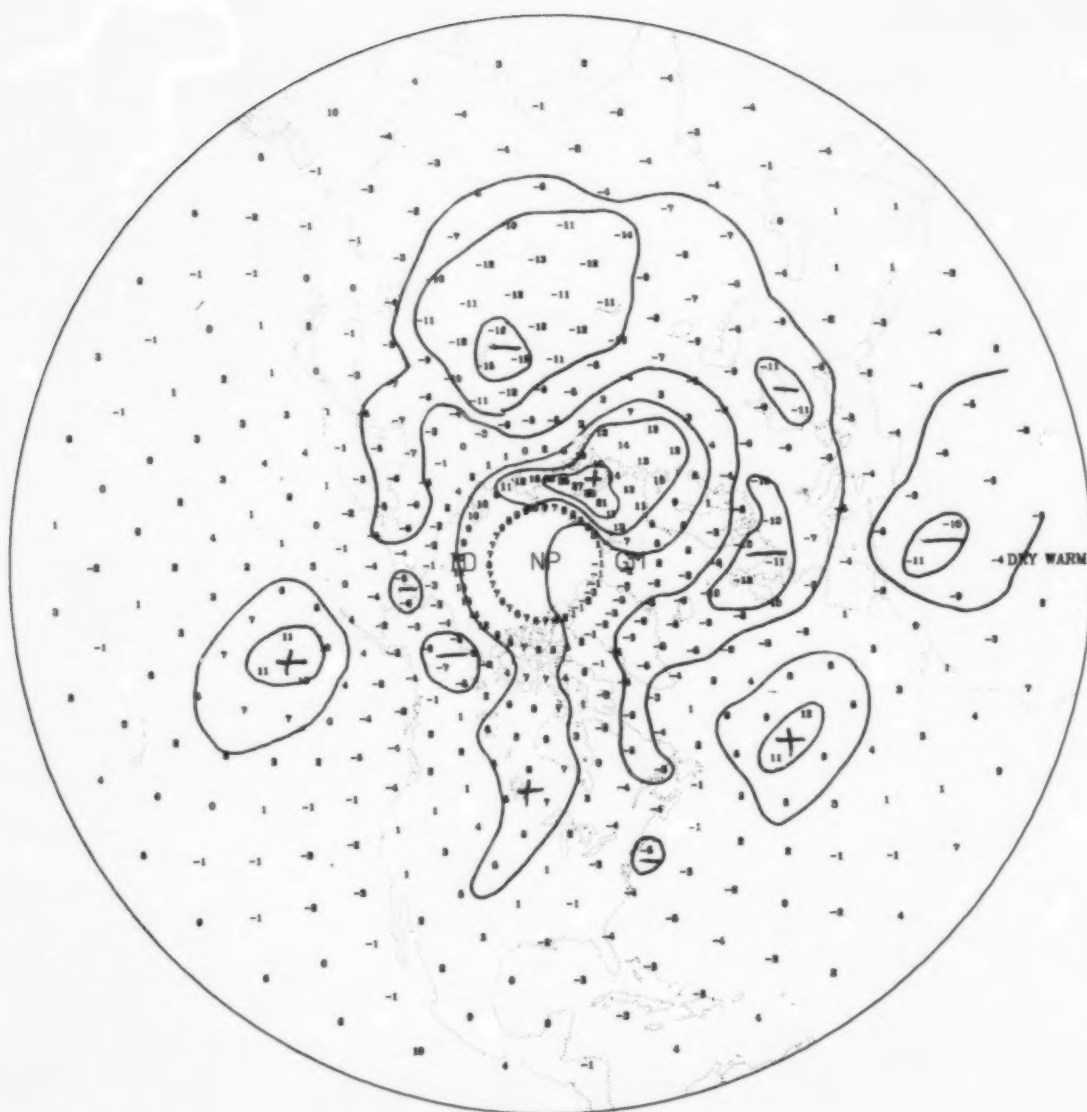


Fig. 21o. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 6, dry warm conditions.

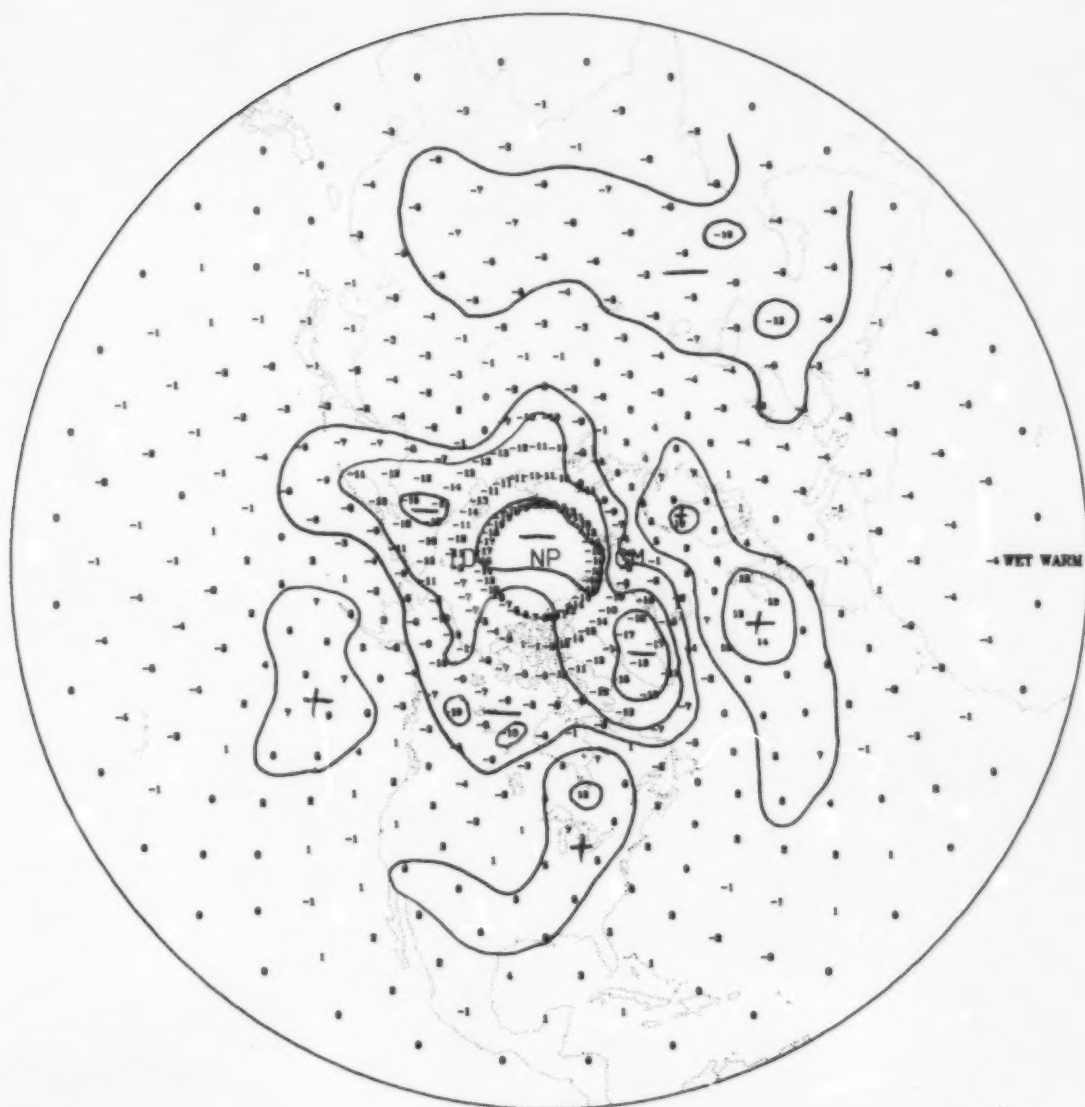


Fig. 21p. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 6, wet warm conditions.

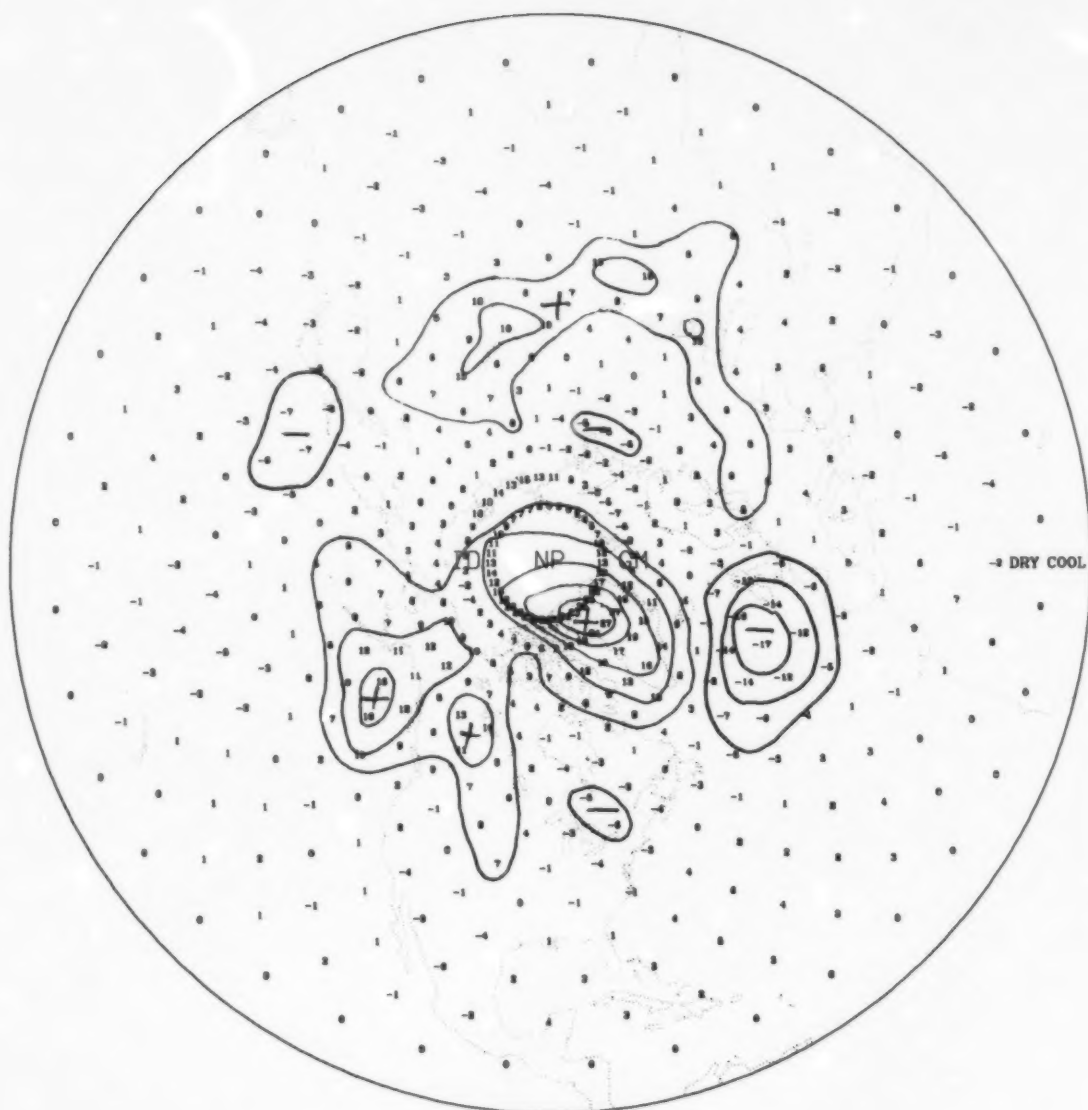


Fig. 21q. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 7, dry cool conditions.

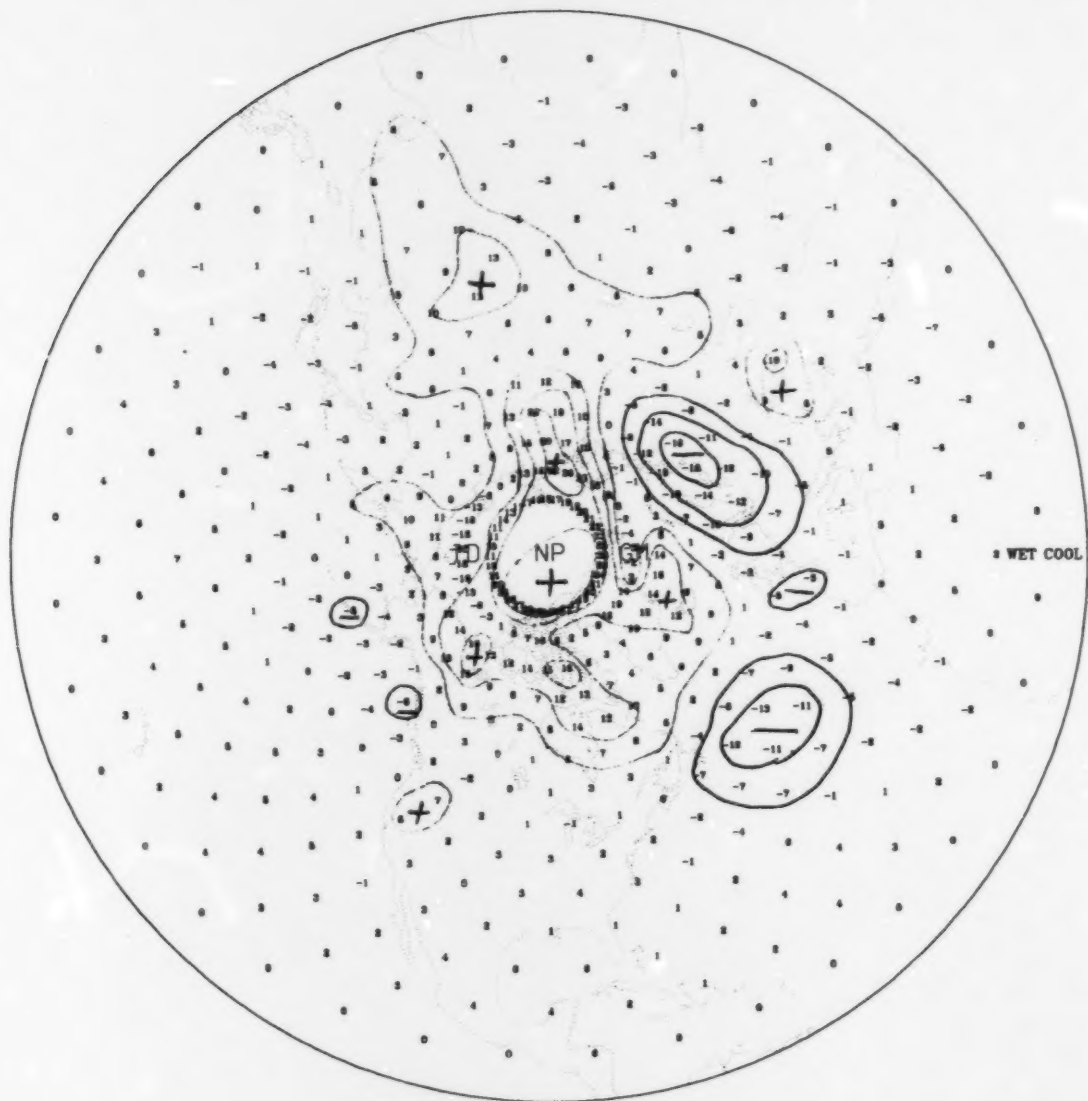


Fig. 21r. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 7, wet cool conditions.

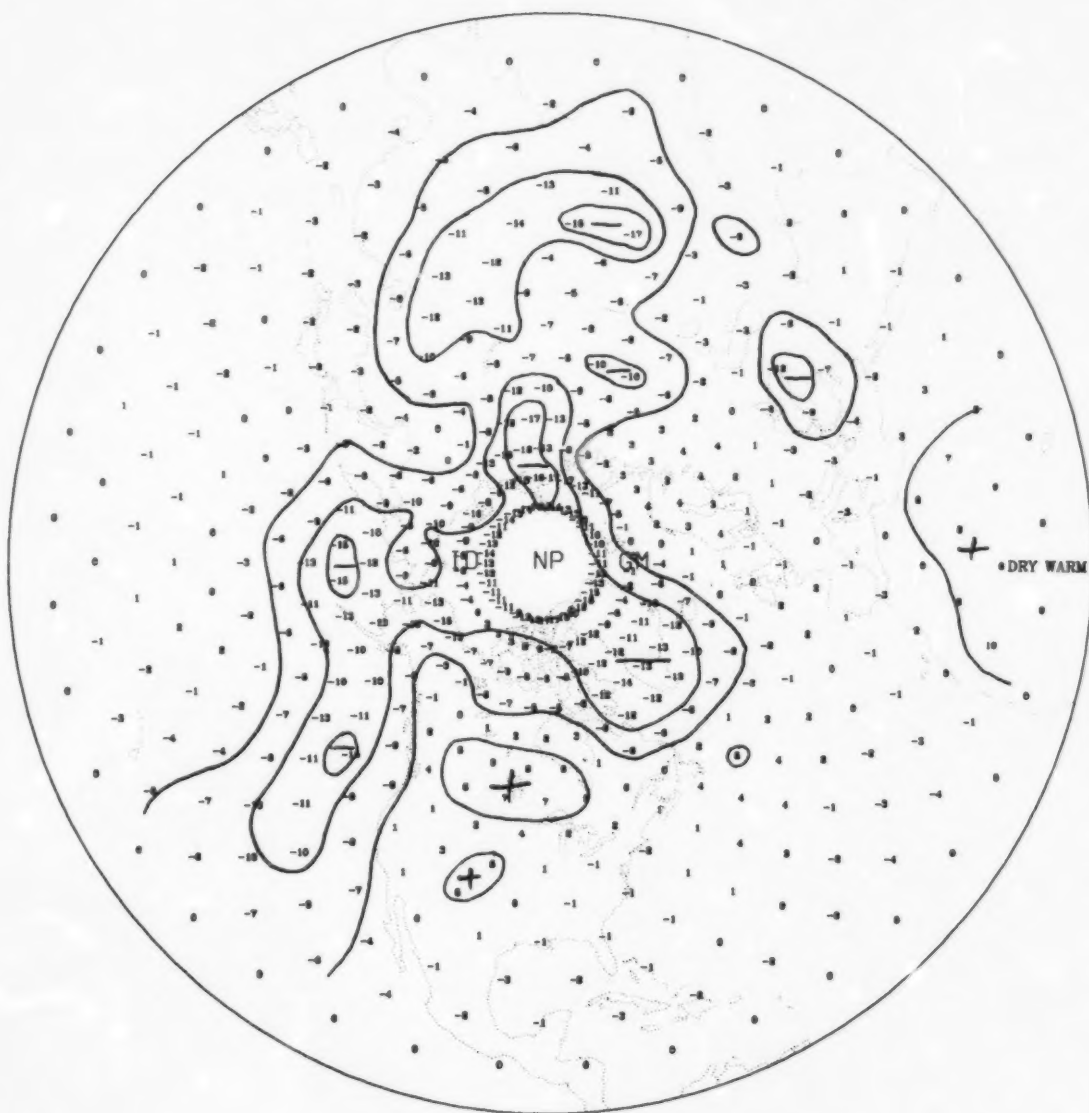


Fig. 21s. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 7, dry warm conditions.

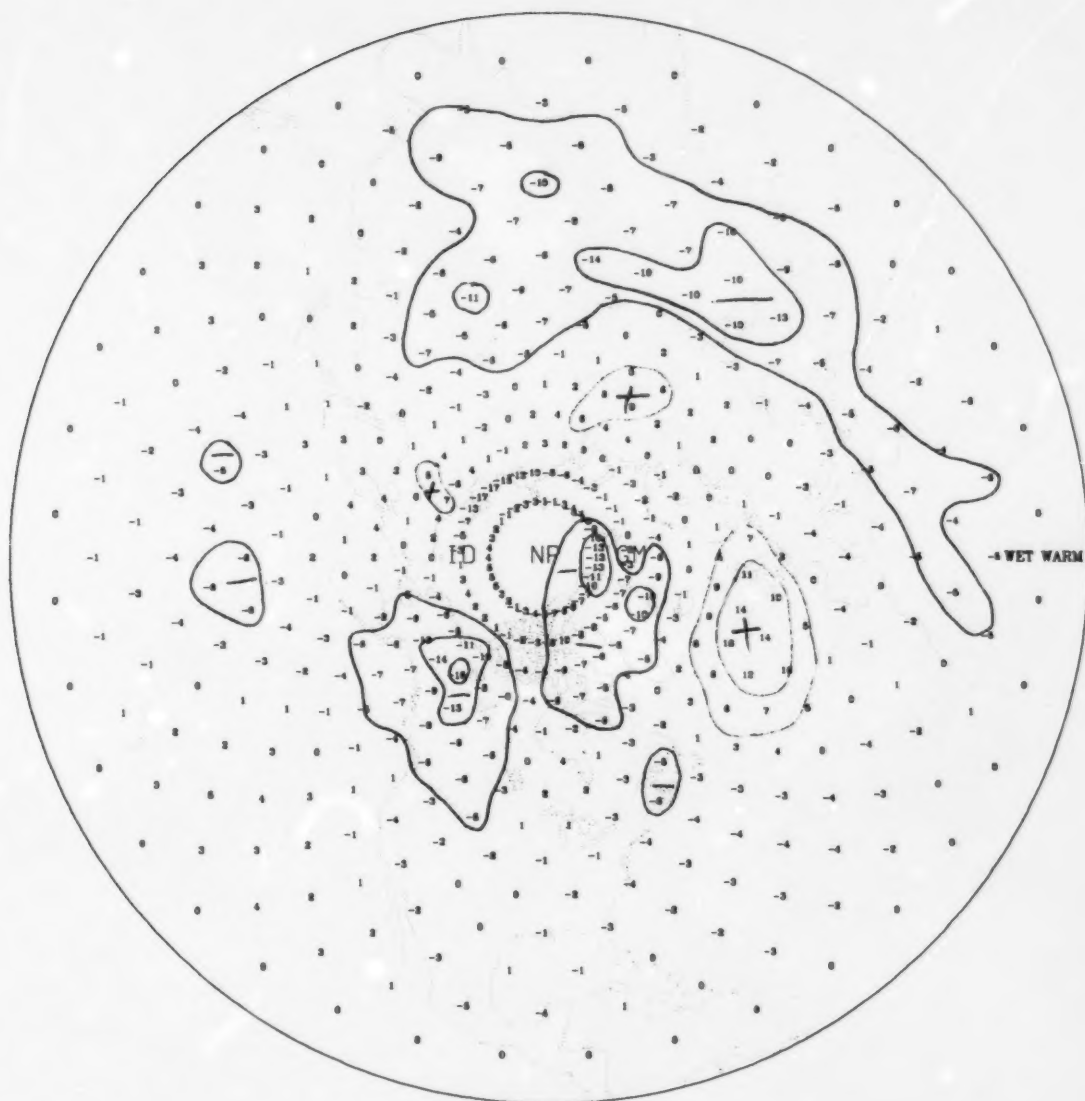


Fig. 21t. Composited northern hemisphere sea-level pressure anomalies for Prairie zone 7, wet warm conditions.

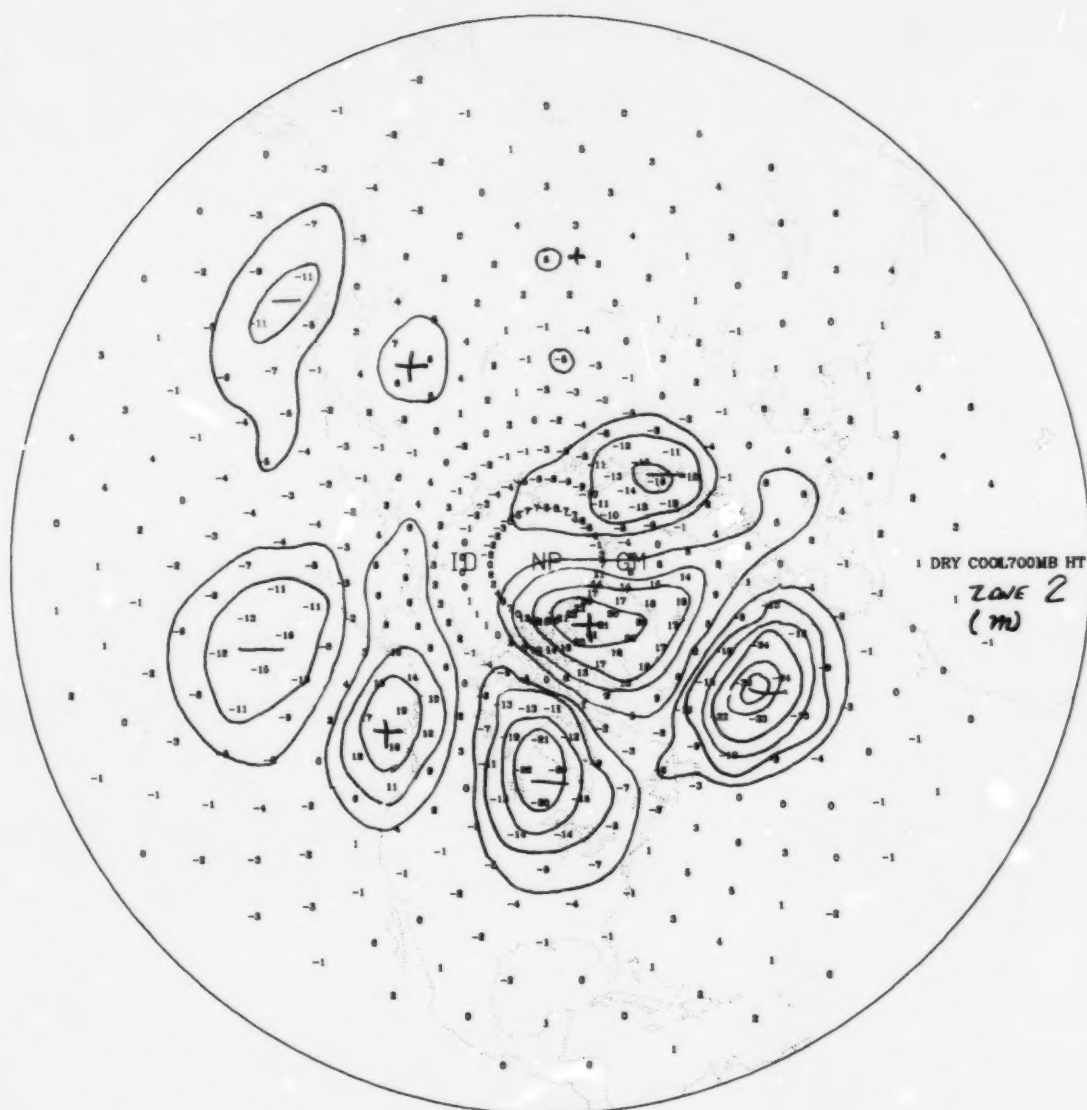


Fig. 22a. Composited northern hemisphere 70-kPa height anomalies for Prairie zone 2, dry, cool conditions.

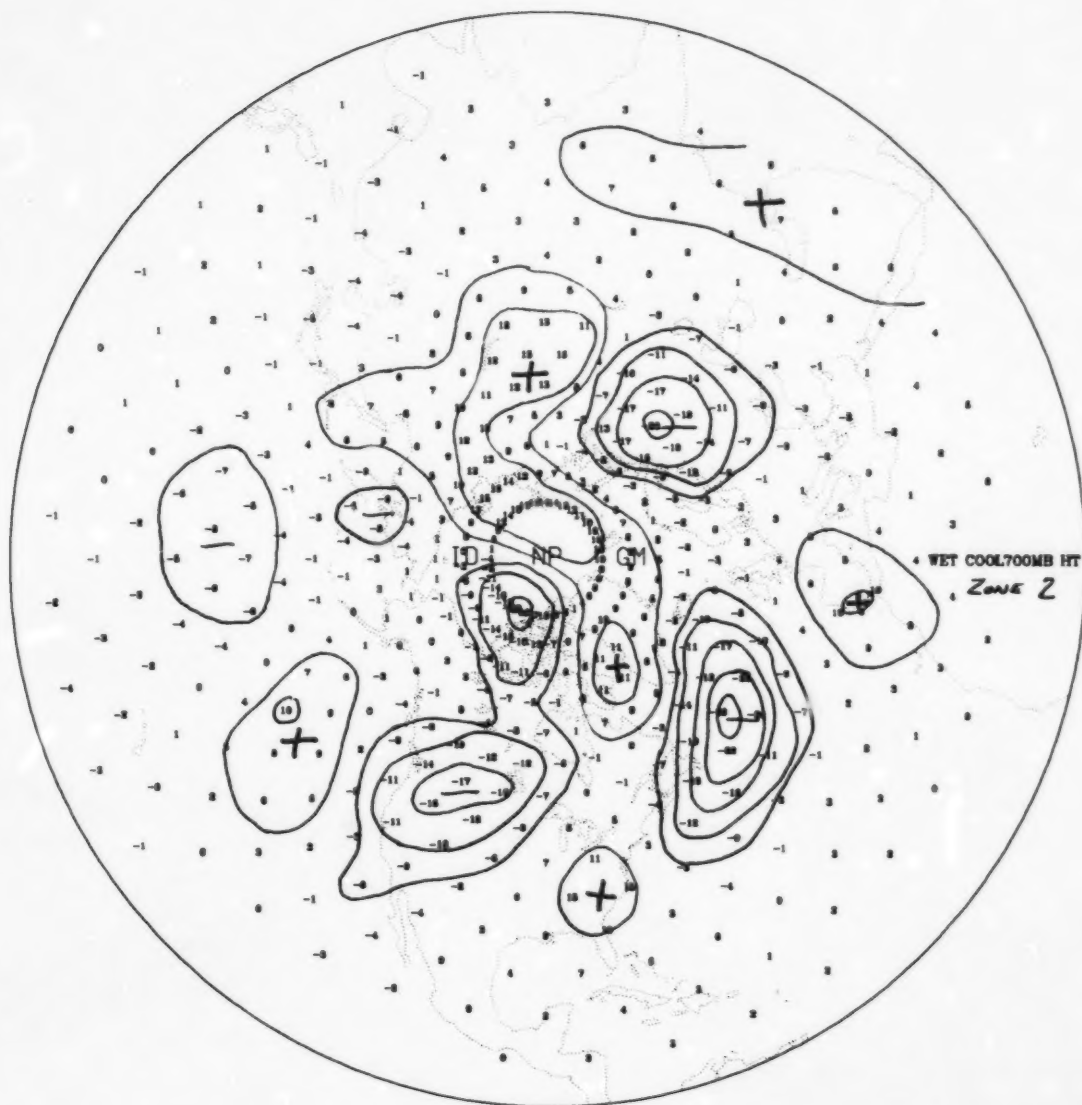


Fig. 22b. Composited northern hemisphere 70-kPa height anomalies for Prairie zone 2, wet, cool conditions.

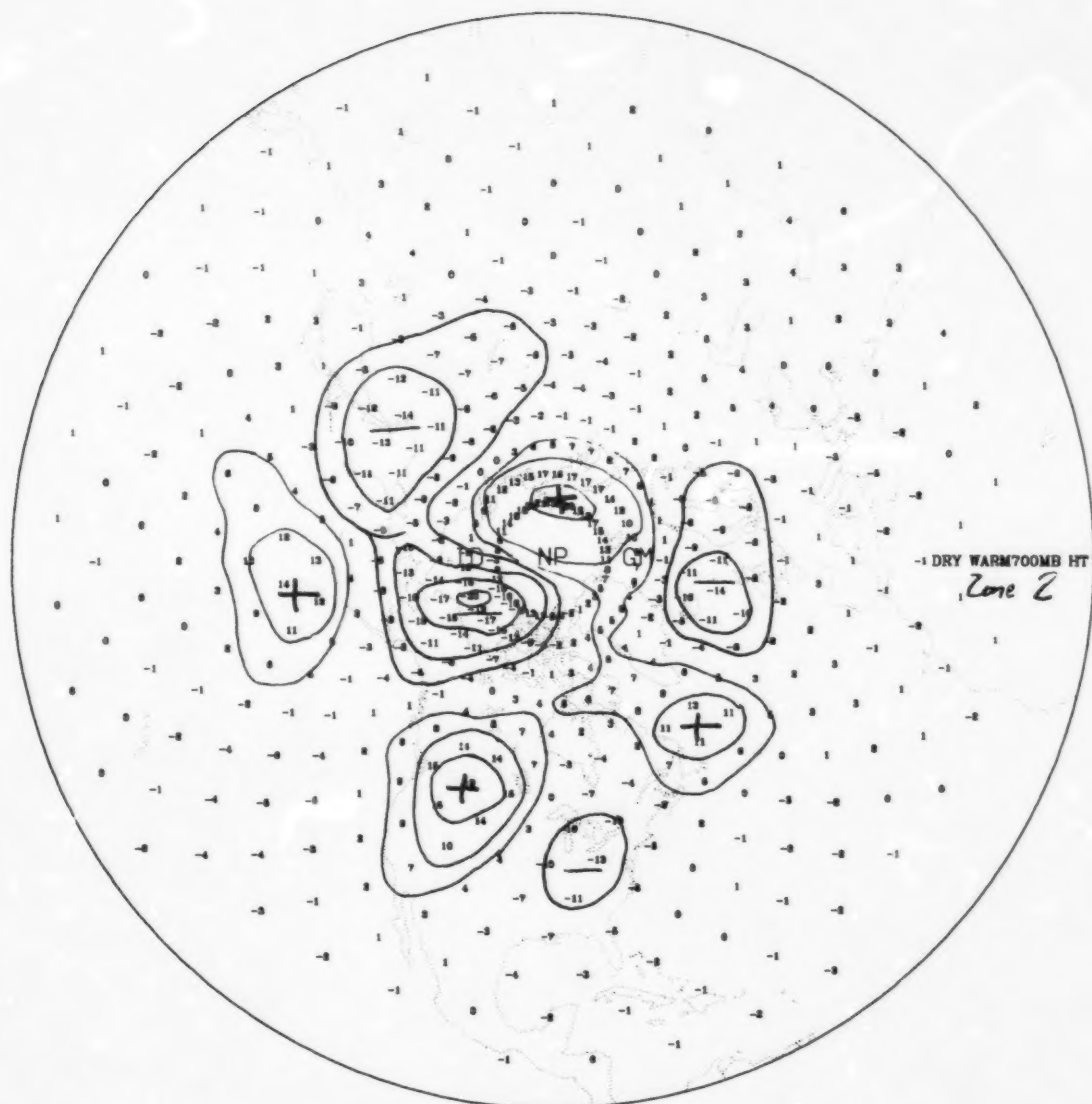


Fig. 22c. Composited northern hemisphere 70-kPa height anomalies for Prairie zone 2, dry, warm conditions.

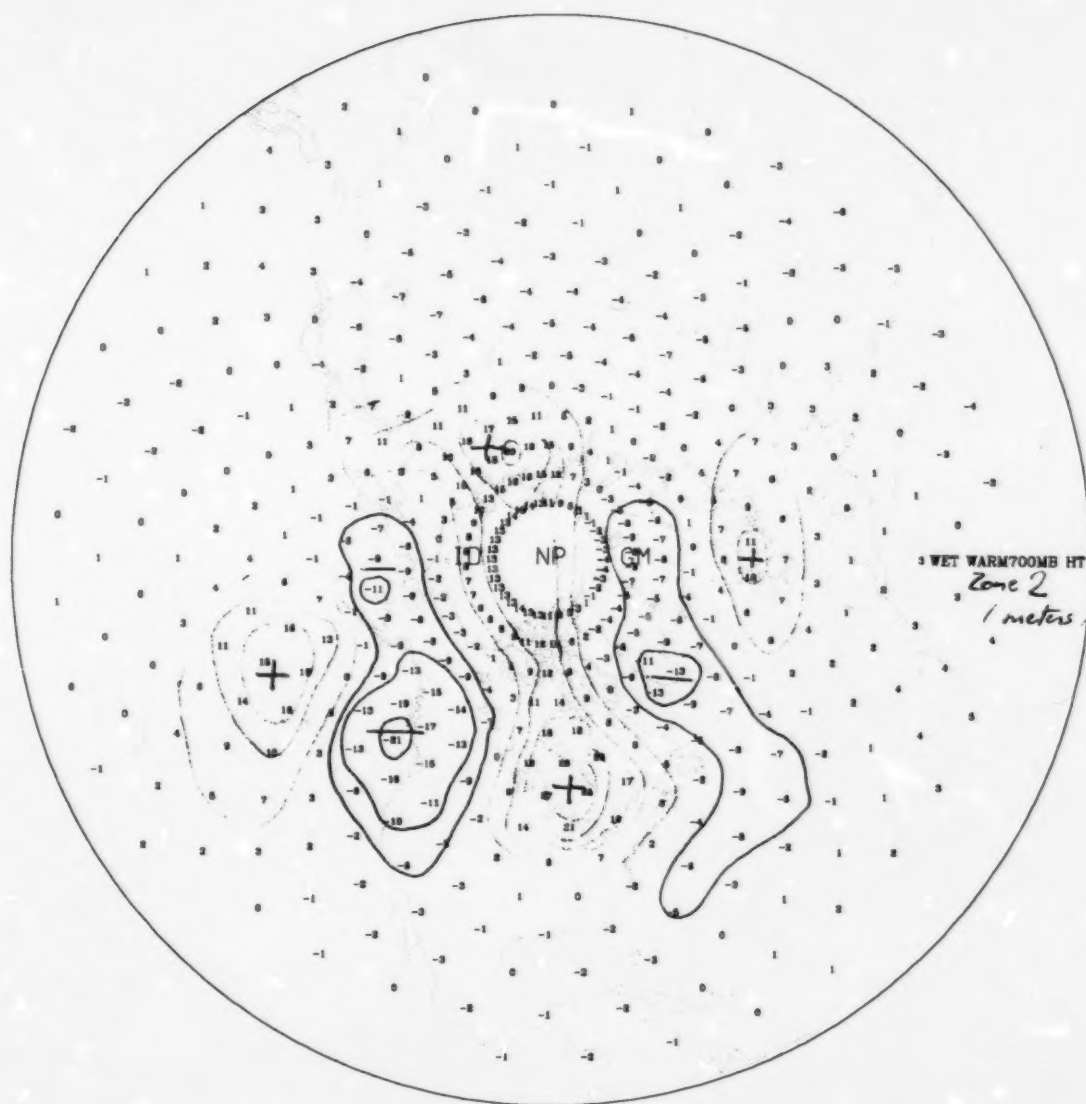


Fig. 22d. Composited northern hemisphere 70-kPa height anomalies for Prairie zone 2, wet, warm conditions.

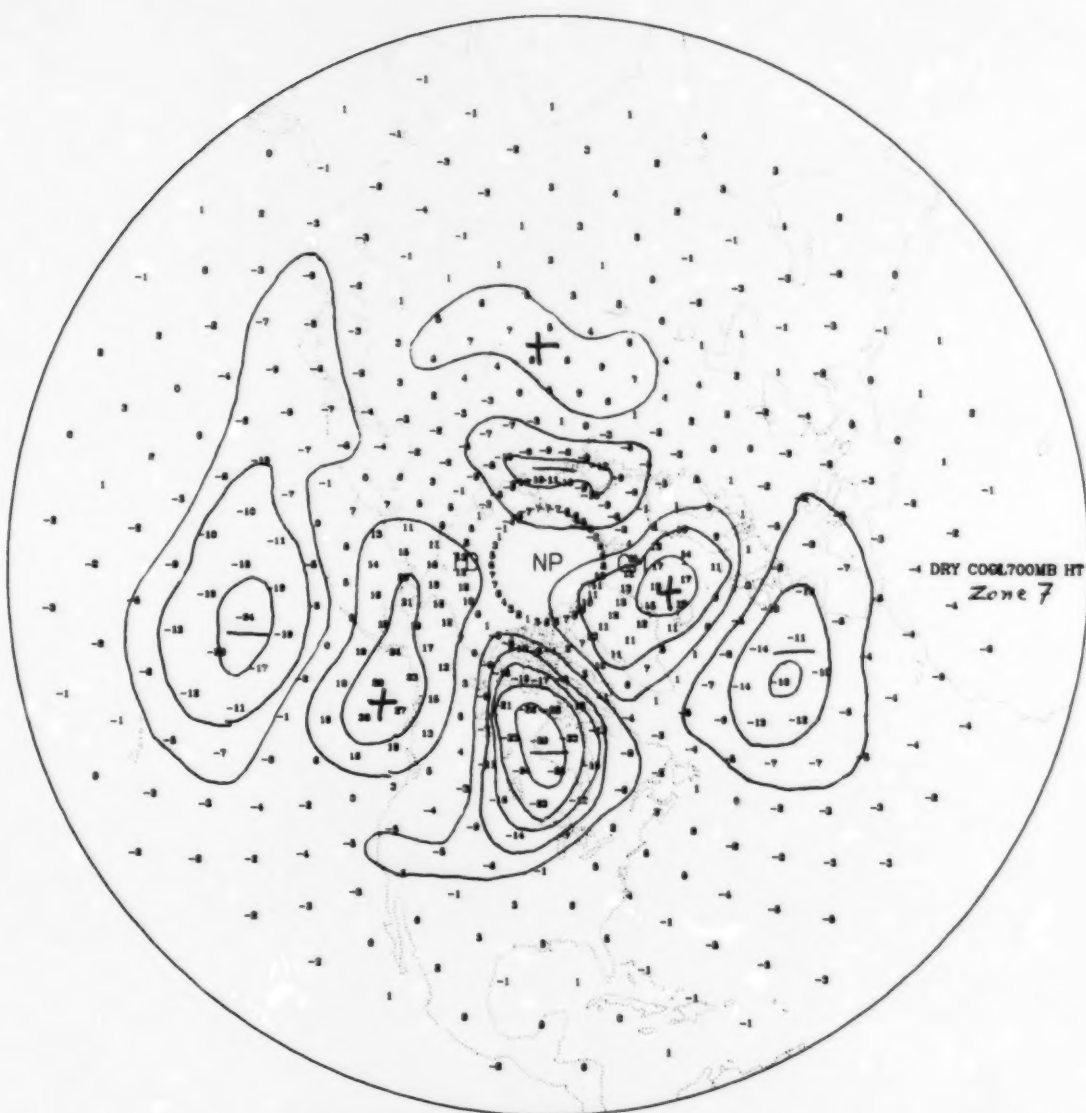


Fig. 22e. Composited northern hemisphere 70-kPa height anomalies for Prairie zone 7, dry, cool conditions.

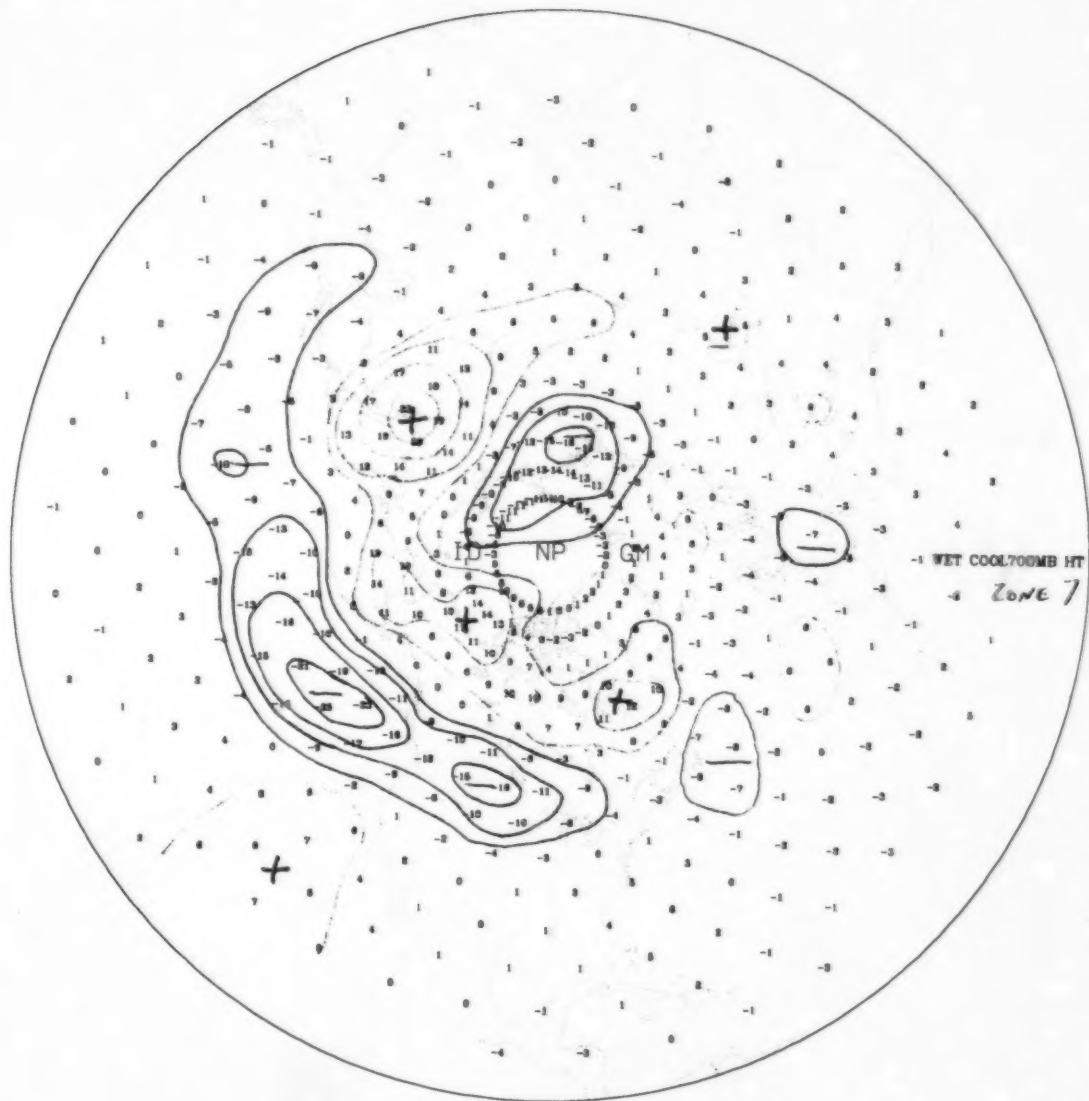


Fig. 22f. Composited northern hemisphere 70-kPa height anomalies for Prairie zone 7, wet, cool conditions.

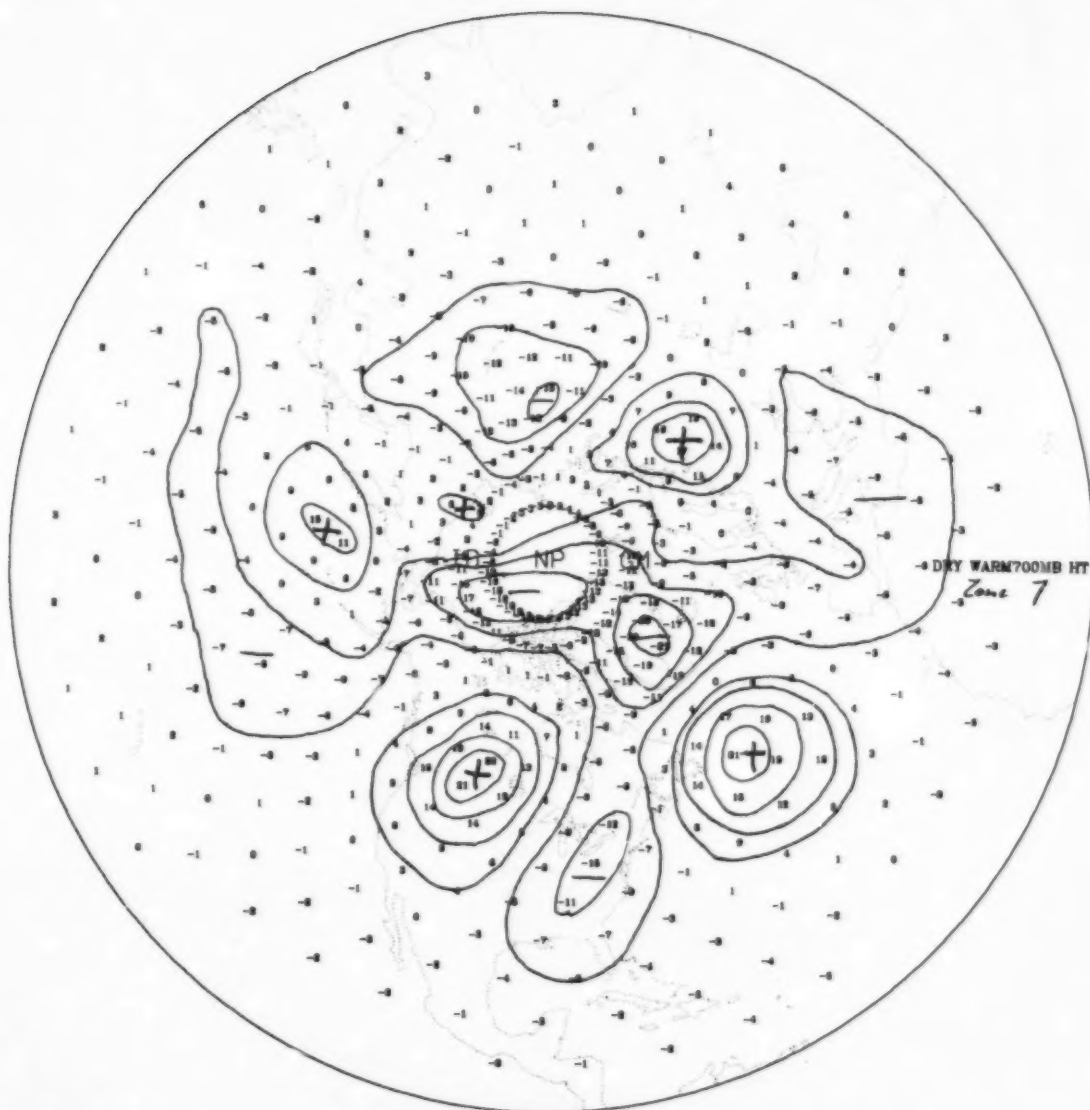


Fig. 22g. Composited northern hemisphere 70-kPa height anomalies for Prairie zone 7, dry, warm conditions.

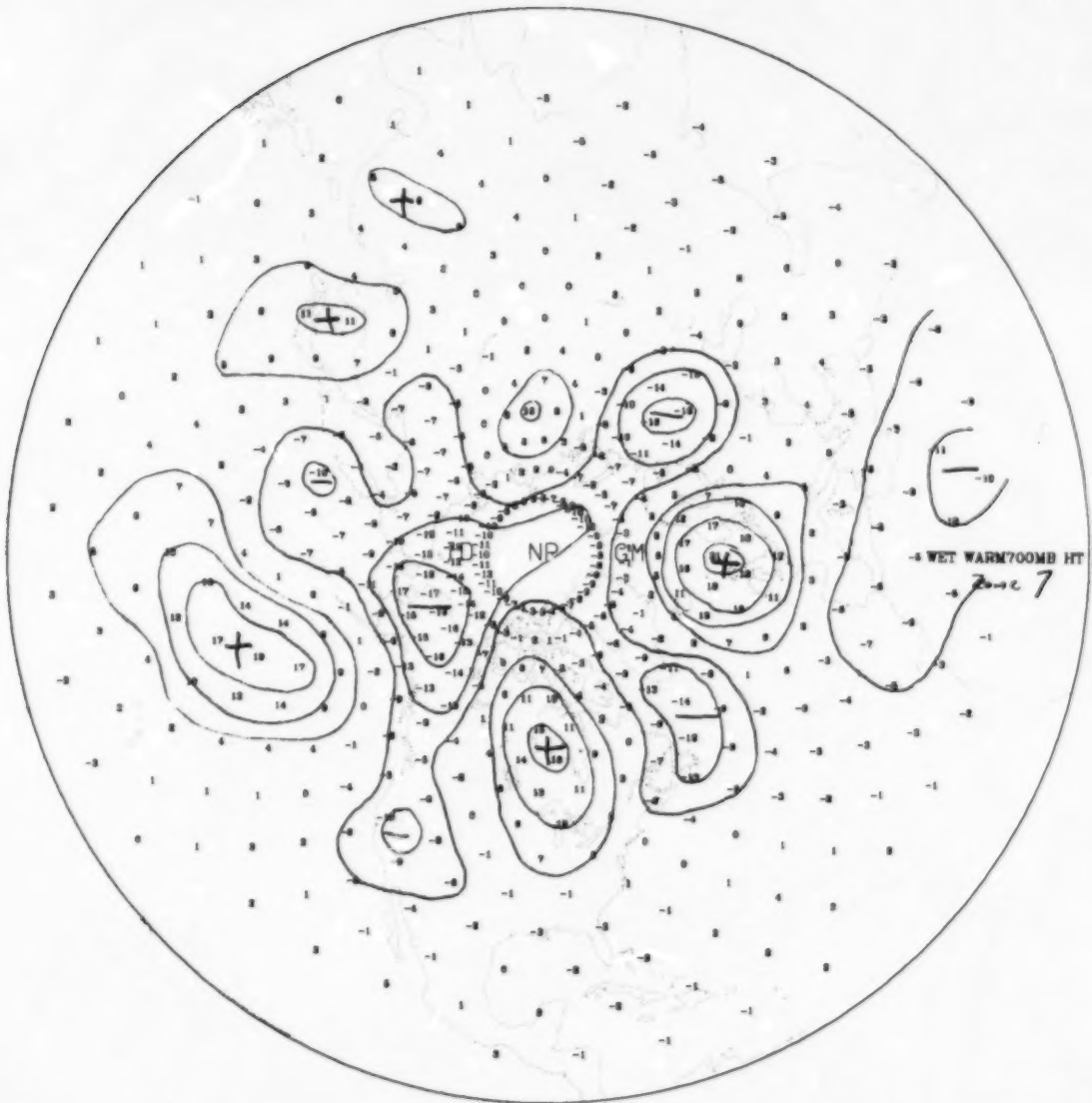


Fig. 22h. Composited northern hemisphere 70-kPa height anomalies for Prairie zone 7, wet, warm conditions.

APPENDIX

CATALOGUE OF DATASETS

<u>Provided</u>	<u>Page</u>
• Monthly Arctic sea-ice concentration	C2
• Monthly northern hemisphere surface temperature anomalies	C7
• Weekly and monthly Arctic snow and sea-ice cover	C11
• Monthly Pacific Ocean sea-surface temperatures	C19
• Monthly Pacific region sea-level pressure	C21
• Monthly northern hemisphere sea-level pressure	C22
• Monthly northern hemisphere 70-kPa heights, and 100-70 kPa thicknesses	C23
• Daily USA/Canada gridded precipitation	C24
• Mean monthly Arctic heat sink indices	C25
—surface temperature anomalies	
—100-70 kPa thickness	
—snow and sea-ice cover	
—sea-ice concentration	
—meridional circulation heat flux	

Recommended but not provided

- Clouds (Hanzis and O'Brien, 1989)
- Outgoing longwave radiation (Gruber et al., 1986)
- ECMWF analyses (Schubert et al., 1990)

Monthly Arctic Sea Ice Concentration

This is provided on a 2400 ft. magnetic tape numbered "ICE408" which is described on the following pages C3-C6. The dataset is described in Walsh (1978) and has been provided by John Walsh of the University of Illinois at Urbana-Champaign.

The monthly data cover the period January 1953 to December 1986, and are in the form of tenths of ice coverage in each of 409 grid squares (1° lat. by 1° long.). The location of the grid points is shown in Figure 1. A description of the dataset is given on pages C3-C5, and a list of relevant further references is on page C6.

Monthly Ice Concentration Grids **January 1953 - December 1986**

Sea ice concentrations for the grid shown in Figure 1 are stored on the enclosed tape. The grids depict ice conditions at the end of each of 408 months (1953-1986 inclusive).

Concentration values are integers representing the number of tenths of ice coverage in each grid area. The grid interval is 1° latitude (60 n mi); the north pole has coordinates (I,J) = (35,35); positive x- and y-axes are 20°W and 70°E.

The tape is 9-track, 6250 bpi, unlabelled, and written in ASCII character format. The record length is 130 characters, and the block length is 6500 characters (50 records). The following formatted FORTRAN READ statement will place an 80 x 58 ice concentration grid into the array ICON(80,58).

```

99      READ(NU,99) MO,MYR,((ICON(I,J),J=1,58),I=1,80)
      FORMAT (40I2)

```

where MO = month (1,2,...,12) and
 MYR = year (1953,1954,...,1986)

The tape contains 409 grids, arranged sequentially as follows:

- 1) Area grid (MO=99, MYR=99 -- see below)
- 2) January 1953 (MO=1, MYR=1953)
- 3) February 1953 (MO=2, MYR=1953)
- .
- .
- .
- 408) November 1986 (MO=11, MYR=1986)
- 409) December 1986 (MO=12, MYR=1986)

The "Area grid" contains the ocean areas corresponding to each grid point. Possible area grid point values are:

- 1,2,...,19,20 number of tenths of 1° latitude square covered by ocean (e.g., 10 = 60x60 n mi²); values exceeding 10 are found near land areas where adjacent grid point(s) lie over land.
- 0 point lies over ocean but not within ice grid area of Figure 1.
- 1 grid point lies over land.

Possible grid point values for the 408 ice concentration grids are:

- 0,1,...,9,10 tenths of grid square area covered by ice.
- 20,21,...,30 values corresponding to 0,1,...,10 tenths of ice coverage, but based on estimated data (see below).
- 1 grid point lies over land.

Estimated values, used in absence of reliable data, are stored in the following areas:

- a) areas where data from more than one source was available, but discrepancies were found between sources.
- b) areas where data from one source was available, but data was labeled as "estimated" by that data source.
- c) areas for which no data was available; grid point values then represent either

- i) concentrations linearly interpolated from prior and following months if data for both prior and following months were available.
- ii) monthly mean values if data for either prior or following month were not available.

Table 1. Ice data sources, listed in order of the most recent.

U. S. Navy Fleet Weather Facility, 1976-77: Arctic Sea Ice Analyses, Eastern and Western (weekly charts), Suitland, MD.

_____, 1976a: Eastern Arctic Sea Ice Analyses, 1972-75. ADA 033344, Suitland, MD.

_____, 1976b: Western Arctic Sea Ice Analyses, 1972-75. ADA 033345, Suitland, MD.

British Meteorological Office, 1959-77: Monthly Ice Charts, HMSO, London (1959 charts in Mariners Weather Log, v. 3-4).

U. S. Naval Oceanographic Office, 1953-71: Report(s) of the Arctic Ice Observing and Forecasting Program. Tech. Reports TR-49 through TR-52, TR-66, TR-69; Special Pubs. SP-70 through SP-81, Washington, DC.

Canadian Meteorological Service, 1966-71: Ice Summary and Analysis, 1964-69 (Yearbooks); Toronto, Ontario.

Arbok Norsk Polarinstitut, Oslo, 1963-71: Sea ice and drift speed observations (Annual reports). Also, T. Lunde, 1963: Ice conditions at Svalbard, 1946-1963, Arbok Norsk Polarinstitut (1963).

Danish Meteorological Institute, 1957-1968: The Ice Conditions in the Greenland Waters (Yearbooks), Charlottenlund, Copenhagen.

U. S. Navy Hydrographic Office, 1958: Oceanographic Atlas of the Polar Seas. Part II. Arctic. H. O. Pub. No. 705, Washington, DC.

Danish Meteorological Institute, 1953-56: The state of the ice in the Arctic Seas. Appendices to Nautical-Meteorological Annuals (Yearbooks), Charlottenlund, Copenhagen.

Jökull, 1953-67: Reports of sea ice off the Icelandic coasts (Annual reports). Icelandic Glaciological Society, Reykjavik.

Monthly Northern Hemisphere Surface Temperature Anomalies

This is provided on a 2400 ft. magnetic tape, numbered "NDP409", which is described on pages C8-C10, following. The tape was obtained from the Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, TN, and was prepared by Jones et al. (1985). It covers the period 1851 to 1988, and represents surface observations that have been gridded (5° lat. by 10° long.) and which are expressed as departures from the 1951-1970 average.

The dataset is described on pages C8-C10, together with a list of relevant references.

MAGNETIC TAPE DESCRIPTIVE FILE

DATASET TITLE: A GLOBAL GRID POINT SURFACE AIR TEMPERATURE DATA
SET: 1851-1988

AUTHORS: P.D. JONES
S.C.B. RAPER
B.S.G. CHERRY
C.M. GOODESS
T.M.L. WIGLEY
B. SANTER
P.M. KELLY
CLIMATIC RESEARCH UNIT
UNIVERSITY OF EAST ANGLIA
NORWICH, UNITED KINGDOM

R.S. BRADLEY
UNIVERSITY OF MASSACHUSETTS
AMHERST, MASSACHUSETTS

H.F. DIAZ
NOAA/ERL
BOULDER, COLORADO

SCOPE OF THE DATA: THE DATA REPRESENT ANOMALIES OF NORTHERN AND SOUTHERN HEMISPHERE 1851-1988 SURFACE AIR TEMPERATURES, RELATIVE TO THE 1951-1970 REFERENCE PERIOD. THE DATA ARE PRESENTED ON A 5-DEGREE LATITUDE BY 10-DEGREE LONGITUDE GRID. THE ORIGINAL STATION DATA HAVE BEEN CHECKED AND CORRECTED TO REMOVE INHOMOGENEITIES, WHERE POSSIBLE.

DATA FORMAT: THE DATA ARE SURFACE AIR TEMPERATURE ANOMALIES IN DEGREES CELSIUS. THE DATA ARE PRESENTED IN TWO FILES: NORTHERN HEMISPHERE AND SOUTHERN HEMISPHERE. SEVEN VARIABLES ARE DEFINED: MONTH, YEAR, LATITUDE, LONGITUDE, SURFACE AIR TEMPERATURE ANOMALY, NUMBER OF STATIONS USED TO CALCULATE EACH GRIDDED ANOMALY, AND THE MEAN VALUE OF THE INVERSE OF THE GREAT CIRCLE DISTANCE BETWEEN THE STATION AND THE GRID POINT. THESE VARIABLES ARE READ BY THE FOLLOWING FORMAT:

```
10      READ(UNIT,10)((IANOM(I,J),I=1,37),J=1,18)
      READ(UNIT,10)((NSTA(I,J),I=1,37),J=1,18)
      READ(UNIT,10)((NDIST(I,J),I=1,37),J=1,18)
      FORMAT(18I6)
```

MISSING VALUES ARE REPRESENTED IN THE TEMPERATURE ANOMALY DATA BY -9999 AND BY 0 IN THE NUMBER OF STATIONS AND MEAN INVERSE DISTANCE DATA.

REFERENCES

- BRADLEY, R.S., P.M. KELLY, P.D. JONES, C.M. GOODESS, AND H. F. DIAZ. 1985. A CLIMATIC DATA BANK FOR NORTHERN HEMISPHERE LAND AREAS, 1851-1980. DOE TECHNICAL REPORT NO. TR017. U.S. DEPARTMENT OF ENERGY, CARBON DIOXIDE RESEARCH DIVISION, WASHINGTON, DC.
- JONES, P.D., S.C.B. RAPER, R.S. BRADLEY, H.F. DIAZ, P.M. KELLY, AND T.M.L. WIGLEY. 1986A. NORTHERN HEMISPHERE SURFACE AIR TEMPERATURE VARIATIONS: 1851-1984. JOURNAL OF CLIMATE AND APPLIED METEOROLOGY 25:161-179.
- JONES, P.D., S.C.B. RAPER, C.M. GOODESS, B.S.G. CHERRY, AND T.M.L. WIGLEY. 1986B. A GRID POINT SURFACE AIR TEMPERATURE DATA SET FOR THE SOUTHERN HEMISPHERE. DOE TECHNICAL REPORT NO. TR027. U.S. DEPARTMENT OF ENERGY, CARBON DIOXIDE RESEARCH DIVISION, WASHINGTON, DC.
- JONES, P.D., S.C.B. RAPER, B. SANTER, B.S.G. CHERRY, C. GOODESS, P.M. KELLY, T.M.L. WIGLEY, R.S. BRADLEY, AND H.F. DIAZ. 1985. A GRID POINT SURFACE AIR TEMPERATURE DATA SET FOR THE NORTHERN HEMISPHERE. DOE TECHNICAL REPORT NO. TR022. U.S. DEPARTMENT OF ENERGY, CARBON DIOXIDE RESEARCH DIVISION, WASHINGTON, DC.
- JONES, P.D., S.C.B. RAPER, AND T.M.L. WIGLEY. 1986C. SOUTHERN HEMISPHERE SURFACE AIR TEMPERATURE VARIATIONS: 1851-1984. JOURNAL OF CLIMATE AND APPLIED METEOROLOGY 25:1213-1230.
- KARL, T.R., AND C.N. WILLIAMS, JR. TIME SERIES SUITABLE FOR THE DETECTION OF CLIMATE CHANGE IN THE UNITED STATES. JOURNAL OF CLIMATE AND APPLIED METEOROLOGY (IN PRESS).
- SMITHSONIAN INSTITUTION. 1927, 1935, 1947. WORLD WEATHER RECORDS. MISCELLANEOUS COLLECTIONS, VOLUMES 79, 90, 104. WASHINGTON, DC.
- U.S. WEATHER BUREAU. 1959-1982. WORLD WEATHER RECORDS. 1941-1950 (1361 PP.), 1951-1960 (VOLUMES 1-6), 1961-1970 (VOLUMES 1-6). U.S. DEPARTMENT OF COMMERCE, WASHINGTON, DC.

C10

CUSTOMER NAME: Ripley, Earle A.

ID: 38

NDP'S REQUESTED:

NDP020-GLOBAL GRID PT SURFACE AIR TEMP 1851-1984

THIS REQUEST REQUIRED 1 TAPE(S)

TAPE VOLUME 1 = NDPT44

TAPE PARAMETERS DENSITY = 6250
 LABEL = NL
 CHARACTER SET = ASCII

TAPE CONTENTS:

VOLUME	FILE #	FILENAME	RECORD LENGTH	BLOCK SIZE
NDPT44	1	NDP020.DESRIPT.FILE	80	8000
NDPT44	2	NDP020.RETRIEVL.PRGM	80	8000
NDPT44	3	NDP020.NORTHGRD.DATA	108	6156
NDPT44	4	NDP020.SOUTHGRD.DATA	108	6156

***** REQUEST COMPLETE *****

CARBON DIOXIDE INFORMATION ANALYSIS CENTER
OAK RIDGE NATIONAL LABORATORY
P.O. BOX 2008 BLDG 1000
OAK RIDGE, TENNESSEE 37831-6335

OPERATED BY

MARTIN MARIETTA ENERGY SYSTEMS

FOR

THE DEPARTMENT OF ENERGY
CARBON DIOXIDE RESEARCH DIVISION

Weekly and Monthly Arctic Snow and Sea-ice Cover

The above is provided on a 2400 ft. magnetic tape, ANSI-labelled "HRDATA", which is described on pages C12-C18. There are a total of 79 files on the tape. The data covers the period November 1966 to December 1988, using a grid of approximately 2° size, varying with latitude. The data were obtained from the World Data Center A for Glaciology [Snow and Ice], Boulder, CO.

The data comprise both snow and ice cover for the period November 1966 to December 1980, but snow only for the remainder of the period, January 1981 to December 1988. The data are derived from satellite observations and are in binary form (snow or ice present or not).

NOAA/NESS Northern Hemisphere Digitized Snow and Ice Cover Data Base

[NOAA/NESS is now NOAA/NESDIS/Interactive Processing Branch]

DOCUMENTATION OF THE COMPUTER DATASETS
ON MAGNETIC TAPE

Supplement to the Final Report:

"Satellite Observations of Variations in
Northern Hemisphere Seasonal Snow Cover"
[NOAA Technical Report NESS 87, 1981]

Kenneth F. Dewey and Richard Heim, Jr.

NOAA/NESS/LSB Grant No. NA80AAA02240

Amended 12/82

Michael Matson and Marilyn Varnadore

NOAA/NESDIS

DOCUMENTATION OF THE COMPUTER DATASETS
ON MAGNETIC TAPE E17282

Kenneth F. Dewey and Richard Heim, Jr.
Climatology Program
Department of Geography
University of Nebraska
Lincoln, NE 68583

This Supplement describes the contents of the digitized data archive prepared by the study, "Satellite Observations of Variations in Northern Hemisphere Seasonal Snow Cover", NOAA/NESS/LSB Grant No. NA 80AAA02240.

The digitized data has been stored on magnetic computer tape E17282. On magnetic tape, data is stored in units called datasets, each being identified by a dataset name and label number. Every dataset on tape E17282 consists of several 80-character-long lines or records.

The 51 datasets residing on tape E17282 can be grouped into three general categories: i) the digital data archives (the weekly and monthly digitized data); ii) miscellaneous information and data; and, iii) computer programs (i.e., software packages) demonstrating how to interpret and use the digitized data. Table 1 summarizes the datasets and briefly describes their contents. The data storage format of the datasets is described in the following paragraphs.

Digital Data Archives: There are two types of digital data archives, the weekly charts that were digitized and the digital monthly charts that were computed from the digitized weekly charts.

The weekly digitized data are stored on the datasets referenced by labels 1 to 16. Two records are used to store every 1 row of weekly data and has the following format:

<u>column</u>	<u>item stored</u>
1-4	year number
5-6	week number
7-8	the J column number
9	a coded indicator ('A' or 'B')
10-54	code indicating presence ('1') or absence ('0') of snow or ice cover for each I coordinate

If column 9 is 'A', columns 10-54 refer to I rows 1 through 45 and if column 9 is 'B', columns 10-53 refer to I rows 46 through 89. The value '9999' in columns 1-4 indicates the end of the week's data.

The digital monthly data are stored on the datasets referenced by labels 25 to 40. Two records are used to store every I row of monthly data. Each record has the following format:

<u>column</u>	<u>item stored</u>
1-4	year number
5-6	month number
7-8	the J column number
9	a coded indicator ('A' or 'B') code
10-54	indicating presence ('1') or absence ('0') of snow or ice cover for each I coordinate

If column 9 is 'A', columns 10-54 refer to I rows 1 through 45 and if column 9 is 'B', columns 10-53 refer to I rows 46 through 89. The value '9999' in columns 1-4 indicates the end of the month's data.

Miscellaneous Information and Data: These datasets contain information needed to help interpret the weekly and monthly digital data.

Dataset A.SNOW.WEEK.DATES (label 17) is a listing of the specific dates (month/day) for each week of each year of the weekly snow and ice cover charts. Also indicated are those weeks for which the weekly charts are missing. Each record has the following format:

<u>column</u>	<u>item stored</u>
1-4	year number
5-6	week number
7-34	the date of the week
35-79	miscellaneous notes
80	a coded indicator ('M' indicates missing map)

Dataset A.SNOW.OPEN.BOUND (label 18) is a listing of those weeks having open boundaries on the weekly snow and ice cover chart. The open boundaries are indicated in one of two ways, both using (I,J) coordinates.

i) '(I₁,J₁) to (I₂,J₂)' indicates there is an open boundary between gridbox coordinates (I₁, J₁) and (I₂,J₂), inclusive.

ii) '(I₃,J₃)' indicates there is an open boundary on gridbox (I₃,J₃).

Each record has the following format:

<u>column</u>	<u>item stored</u>
1-4	year number
5-6	week number
7-80	the open boundaries

Dataset A.MONTH.WEEKS (label 41) lists the weekly charts that were used to compute each monthly chart. Each record has the following format:

<u>column</u>	<u>item stored</u>
1-4	year number
5-6	month number
7-8	the number of weeks comprising the month
9-18	the weeks (by identification number, 1-53) used to compute the monthly charts.

Dataset A.GRIDBOX.AREAS (label 24) describes the gridboxes. Each record identifies the I and J coordinates of a gridbox, the area represented by the gridbox, and the latitude and longitude of the gridbox.

The geography grid matrices are stored on the datasets referenced by labels 20 and 21 and 44 to 51. Each dataset contains the gridbox coordinates

of the land or water geography used in conjunction with the digitized data to distinguish between snowcover and ice-cover. Every geography grid data-set record has the following format:

<u>column</u>	<u>item stored</u>
7-8	I row number
9-10	the number of patches of geography
11-78	the J range of each geography patch

The last record of each dataset has the number, '9999', coded in columns 1-4 to indicate the end of the geography grid.

Computer Programs: Five FORTRAN computer programs have been included to demonstrate how the digitized weekly and monthly data can be interpreted and how the monthly digital data was computed. Each program is well documented and should be self-explanatory. The programs are summarized below.

Dataset A.SNOW.DATA.PRINT (label 19) contains a program that simply lists the digitized weekly snow and ice cover data in columnar form.

Dataset PRINT.SNOW (label 22) contains a program that demonstrates how the land geography grid is combined with the weekly digitized data to produce a weekly snowcover map.

Dataset PRINT. SNOW.ICE (label 23) contains a program that demonstrates how the land and water geography grids are combined with the weekly digitized data to produce a weekly snow and ice cover map.

Dataset A.SNOW.MONTH (label 42) contains the program used to compute the monthly charts.

Dataset PRINT.MONTH.S.I (label 43) contains a program that demonstrates how the land and water geography grids are combined with the monthly digital data to produce a monthly map. This program has the option of displaying either snowcover or ice-cover independently or both snowcover and ice-cover on the same map. NOTE: No ice data was digitized beginning with the 1981 data.

LABEL NUMBER	DATASET NAME	DESCRIPTION OF CONTENTS
1	A.SNOW.DATA.Y1966	DIGITIZED WEEKLY DATA FOR 1966
2	A.SNOW.DATA.Y1967	DIGITIZED WEEKLY DATA FOR 1967
3	A.SNOW.DATA.Y1968	DIGITIZED WEEKLY DATA FOR 1968
4	A.SNOW.DATA.Y1969	DIGITIZED WEEKLY DATA FOR 1969
5	A.SNOW.DATA.Y1970	DIGITIZED WEEKLY DATA FOR 1970
6	A.SNOW.DATA.Y1971	DIGITIZED WEEKLY DATA FOR 1971
7	A.SNOW.DATA.Y1972	DIGITIZED WEEKLY DATA FOR 1972
8	A.SNOW.DATA.Y1973	DIGITIZED WEEKLY DATA FOR 1973
9	A.SNOW.DATA.Y1974	DIGITIZED WEEKLY DATA FOR 1974
10	A.SNOW.DATA.Y1975	DIGITIZED WEEKLY DATA FOR 1975
11	A.SNOW.DATA.Y1976	DIGITIZED WEEKLY DATA FOR 1976
12	A.SNOW.DATA.Y1977	DIGITIZED WEEKLY DATA FOR 1977
13	A.SNOW.DATA.Y1978	DIGITIZED WEEKLY DATA FOR 1978
14	A.SNOW.DATA.Y1979	DIGITIZED WEEKLY DATA FOR 1979
15	A.SNOW.DATA.Y1980	DIGITIZED WEEKLY DATA FOR 1980
16	A.SNOW.DATA.Y1981	DIGITIZED WEEKLY DATA FOR 1981
17	A.SNOW.WEEK.DATES	MISC. DATA: WEEK DATES
18	A.SNOW.OPEN.BOUND	MISC. DATA: OPEN BOUNDARIES
19	A.SNOW.DATA.PRINT	PROGRAM: PRINT WEEKLY DATA
20	GEOGGRID.NHLAND	NORTHERN HEMISPHERE LAND GEOGRAPHY GRID
21	GEOGRID.NHWATER	NORTHERN HEMISPHERE WATER GEOGRAPHY GRID
22	PRINT.SNOW	PROGRAM: DISPLAY WEEKLY SNOWCOVER
23	PRINT.SNOW.ICE	PROGRAM: DISPLAY WEEKLY SNOW/ICE COVER
24	A.GRIDBOX.AREAS	MISC. DATA: GRIDBOX AREAS, LATITUDES, LONGITUDES
25	A.MONTH.Y1966	DIGITAL MONTHLY DATA FOR 1966
26	A.MONTH.Y1967	DIGITAL MONTHLY DATA FOR 1967
27	A.MONTH.Y1968	DIGITAL MONTHLY DATA FOR 1968
28	A.MONTH.Y1969	DIGITAL MONTHLY DATA FOR 1969
29	A.MONTH.Y1970	DIGITAL MONTHLY DATA FOR 1970
30	A.MONTH.Y1971	DIGITAL MONTHLY DATA FOR 1971
31	A.MONTH.Y1972	DIGITAL MONTHLY DATA FOR 1972
32	A.MONTH.Y1973	DIGITAL MONTHLY DATA FOR 1973
33	A.MONTH.Y1974	DIGITAL MONTHLY DATA FOR 1974
34	A.MONTH.Y1975	DIGITAL MONTHLY DATA FOR 1975
35	A.MONTH.Y1976	DIGITAL MONTHLY DATA FOR 1976
36	A.MONTH.Y1977	DIGITAL MONTHLY DATA FOR 1977
37	A.MONTH.Y1978	DIGITAL MONTHLY DATA FOR 1978
38	A.MONTH.Y1979	DIGITAL MONTHLY DATA FOR 1979
39	A.MONTH.Y1980	DIGITAL MONTHLY DATA FOR 1980
40	A.MONTH.Y1981	DIGITAL MONTHLY DATA FOR 1981
41	A.MONTH.WEEKS	MISC. DATA: WEEKS COMPRISING THE MONTHS
42	A.SNOW.MONTH	PROGRAM: COMPUTE MONTHLY CHARTS
43	PRINT.MONTH.S.I	PROGRAM: DISPLAY MONTHLY SNOW/ICE COVER
44	GEOGGRID.NAMERICA	NORTH AMERICA GEOGRAPHY GRID
45	GEOGGRID.EURASIA	EURASIA GEOGRAPHY GRID
46	GEOGGRID.ARTIC	ARCTIC OCEAN GEOGRAPHY GRID
47	GEOGGRID.HUDSON	HUDSON BAY GEOGRAPHY GRID
48	GEOGGRID.GLAKES	GREAT LAKES GEOGRAPHY GRID
49	GEOGGRID.OKHOTSK	SEA OF OKHOTSK GEOGRAPHY GRID
50	GEOGGRID.LAND	ALL LAND AREAS WITHIN THE I-J GRID
51	GEOGGRID.WATER	ALL WATER BODIES WITHIN THE I-J GRID

TAPE IS: 9TK, SL DEN = 1600
 DCB = (RECFM = FB, LRECL = 80, BLKSIZE = 800)

ASNOWDATA.Y1966;1	ASNOWDATA.Y1967;2	ASNOWDATA.Y1968;1	ASNOWDATA.Y1969;1
ASNOWDATA.Y1970;1	ASNOWDATA.Y1971;1	ASNOWDATA.Y1972;1	ASNOWDATA.Y1973;1
ASNOWDATA.Y1974;1	ASNOWDATA.Y1975;1	ASNOWDATA.Y1976;1	ASNOWDATA.Y1977;1
ASNOWDATA.Y1978;1	ASNOWDATA.Y1979;1	ASNOWDATA.Y1980;1	ASNOWDATA.Y1981;1
ASNOWWEEKDATES.66 81;1		ASNOW.OPENBOUND;1	ASNOWDATA.PRINT;1
GEOGGRID.NHLAND;1	GEOGGRID.NHWATER;1	PRINT.SNOW;1	PRINT.SNOWICE;1
AGRIDBOX.AREAS;1	AMONTH.Y1966;1	AMONTH.Y1967;1	AMONTH.Y1968;1
AMONTH.Y1969;1	AMONTH.Y1970;1	AMONTH.Y1971;1	AMONTH.Y1972;1
AMONTH.Y1973;1	AMONTH.Y1974;1	AMONTH.Y1975;1	AMONTH.Y1976;1
AMONTH.Y1977;1	AMONTH.Y1978;1	AMONTH.Y1979;1	AMONTH.Y1980;1
AMONTH.Y1981;1	AMONTH.WEEKS;1	ASNOW.MONTH;1	PRINT.MONTH SI;1
GEOGGRID.NAMERICA;1	GEOGGRID.EURASIA;1	GEOGGRID.ARTIC;1	GEOGGRID.HUDSON;1
GEOGGRID.GLAKES;1	GEOGGRID.OKHOTSK;1	GEOGGRID.LAND;1	GEOGGRID.WATER;1
ASNOWDATA.Y1982;2	ASNOWWEEKDATES.1982;1		AMONTH.Y1982;1
AMONTH.WEEKS1982;1	ASNOWDATA.Y1983;1	ASNOWWEEKDATES.1983;1	
AMONTH.Y1983;1	AMONTH.WEEKS1983;1	ASNOWDATA.Y1984;1	ASNOWWEEKDATES.1984;1
AMONTH.Y1984;1	AMONTH.WEEKS1984;1	ASNOWDATA.Y1985;1	ASNOWWEEKDATES.1985;1
AMONTH.Y1985;1	AMONTH.WEEKS1985;1	ASNOWDATA.Y1986;1	ASNOWWEEKDATES.1986;1
AMONTH.Y1986;1	AMONTH.WEEKS1986;1	ASNOWDATA.Y1987;1	ASNOWWEEKDATES.1987;1
AMONTH.Y1987;1	AMONTH.WEEKS1987;1	ASNOWDATA.Y1988;1	ASNOWWEEKDATES.1988;1
AMONTH.Y1988;1	AMONTH.WEEKS1988;1		

Total of 79 files.

Monthly Pacific Ocean Sea-surface Temperatures

This dataset is described on the following page, and is a 372 kB file ("PSSTMVL.DAT") on diskette "HRDDROUGHT1". It covers the Pacific region between latitudes 20°N and 60°N, longitudes 110°W and 130°E (5° lat. by 5° long. grid), for the period January 1947 to June 1988. The dataset is discussed in Namias et al. (1988).

This dataset was obtained from Dan Cayan at the Scripps Institution of Oceanography.

```

10688      396391376380381378411432451472493485
20688      418402397395413425414430454456465473484491508
30688      418411403415412417421435437440444446448448462479499519546
40688      460434441437427428445453451464467473481478488506520537560
50688      565590588570537534523541552563570565554550549561568577582555
60688      730714715687663653655671673675684687667662642635641638646631599584
706888784761745737746754743759764764774766767756741729722711688666656641638667
80688809809815812834834816812812798813802799790782773750744732709692681673674695
90688857853844848852850843829831808816800799800793771756751730725718729727725715

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8/18/88

INFO ABOUT PSSTMVL.DAT (ABOVE SAMPLE IS FOR JUNE, 1988)

CONTENTS:

NORTH PACIFIC SEA SURFACE TEMPERATURE MONTHLY VALUES FOR THE
PERIOD JANUARY, 1947 - JUNE, 1988 AND FOR THE AREA COVERING
[60N - 20N, 130E - 110W].

**** MISSING DATA IS DENOTED BY BLANKS

FORMAT:

EACH MONTH IS REPRESENTED BY A 9 X 25 ARRAY (9 LATITUDES AND
25 LONGITUDES), WHERE RECORD 1 REPRESENTS DATA AT 60N AND
RECORD 9 REPRESENTS DATA AT 20N.

RECORD NO	I1	1 - 9
MONTH	I2	1 - 12
LAST 2 DIGITS OF YEAR	I2	47 - 88
25 LONG POINTS	25I3	

UNITS:

THE VALUES ARE IN DEGREES FAHRENHEIT AND MUST BE DIVIDED BY
10 TO GET TRUE VALUE (I.E. 396 = 39.6 DEG F)

WRITTEN BY: DAN CAYAN, CLIMATE RESEARCH GROUP
SCRIPPS INSTITUTION OF OCEANOGRAPHY
UNIVERSITY OF CALIFORNIA, SAN DIEGO
LA JOLLA, CALIFORNIA 92093-0224

Monthly Pacific Region Sea-level Pressure

This dataset is contained in a 782 kB file ("HISTSLP.DAT") , which is provided on diskette "HRDDROUGHT2". It covers the period January 1899 to December 1987 (5° lat. by 5° long. grid).

HISTSLP.DAT is an ASCII file of 80 characters per line. The format is (I1,2I2,25I3). The layout is essentially the same as for PSSTMVL.DAT (see page C19). Data values are in hPa and have had 900 subtracted. Missing values are encoded 900.

This dataset was obtained from Dan Cayan at the Scripps Institution of Oceanography.

Monthly Northern Hemisphere Sea-level Pressure

This is a 2.47 MB file ("HSLPMVL.DAT"), provided on diskettes "HRDDROUGHT3" and "HRDDROUGHT4" in backup format (the OS/2, and perhaps DOS, Restore command may be used to transfer the file to a hard disk). The gridded (5° lat. by 5° long.) data cover the period December 1946 to June 1989.

HSLPMVL.DAT is an ASCII file of format (3I2,6X,14I4). The first three fields are:

- longitude (subtract 1 and multiply by 5 to get values west of Greenwich),
- month, and
- year.

The pressure values are coded as for the previous file, and missing values may also be blank. The 14 latitude values start at 80°N on the left and go down to 15°N on the right. Most of the gridded values are in a "checkerboard" pattern, with the black squares missing (i.e. a diamond grid pattern).

This dataset was obtained from Dan Cayan at the Scripps Institution of Oceanography.

Monthly NH 70 kPa heights, and 100-70 kPa Thicknesses

These data are expressed both as actual values (files "H700MVL.DAT" and "HTHKMVL.DAT") and as departures from the mean ("H700MDM.DAT" and "HTHKMDM.DAT"). All four files are provided on tape "HRDATA" described on page C11.

H700MVL.DAT, H700MDM.DAT, HTHKMVL.DAT, and HTHKMDM.DAT are ASCII files in the same format as the previous file. Height and thickness values must have 700 added to them to get values in tens of feet.

This dataset was obtained from Dan Cayan at the Scripps Institution of Oceanography.

Daily USA/Canada Gridded Precipitation

This dataset was compiled at Scripps Institution of Oceanography by John Roads and Earle Ripley. It is provided as file "USCANPPT.BIN" on diskette "HRDDROUGHT1".

USCANPPT.BIN is a binary file of monthly gridded precipitation values for Canada and the U.S.A. The 2° latitude by 4° longitude grid covers the region 24° - 70°N, 54° - 138°W. The units are tenths of millimetres and missing data are encoded -999. The format of the binary file, and other useful information may be found in the Fortran code listing USCANPPT.FOR (provided).

Arctic Heat Sink Indices

The following five files represent monthly time series of the AHS indices used in the Analysis section of this study. They have been calculated for the north polar region, and are provided in ASCII format on diskette "HRDDROUGHT2".

- Mean monthly Arctic surface temperature anomalies -- 1854 to 1988 (file "ARCTEMP.DAT").
- Mean monthly Arctic 100 - 70 kPa thickness -- 1946 to 1989 (file "THICK.DAT").
- Mean monthly Arctic snow plus sea ice cover -- 1966 to 1980, and snow only -- 1981 to 1988 (file "ARCSNOW.DAT").
- Mean monthly Arctic sea-ice concentration -- 1953 to 1986 (file "ARCICE.DAT").
- Mean monthly meridional circulation heat flux into the Arctic -- 1946 to 1989 (file "MMCIRC.DAT").